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The Abacá Plant and Its Fiber, Manila Hemp

Production of Manila hemp, the world's foremost cordage fiber, was a Philippine monopoly from the early nineteenth century, when it was introduced into world trade, until 1930. Since then commercial plantings have been established in several other countries, but over 90% of all abacá production still comes from the Philippines. World production of the fiber in 1951 amounted to about 200,000 tons.

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Introduction

Tracing each of the plant fibers commercially important in the present day world reveals an interesting history of trial and error, failure and success. Each of these fibers was originally developed from a wild plant by a people of simple culture who sought a useful fiber for general service. Many source plants were tried by early man, but only a few became so widely accepted and culturally developed as to become common domesticated plants in various regions of the earth. Abacá, known in modern international trade as "Manila hemp" and botanically designated *Musa textilis* Neé, nicely illustrates this complex history. As a wild plant native to the Philippine Islands and northern Borneo, *Musa textilis* was domesticated by Filipinos. A fiber, generally known among them as "abacá", was prepared from it, used and traded for centuries as a monopoly product. Repeated efforts have been made to move the plant to other parts of the earth for fiber-producing purposes, but until quite recent years none of these efforts was really successful. The earlier failures resulted from ignorance about the plant, its habits and its environmental requirements.

The Plant and Its Preferred Habitat

The abacá plant is a member of a large genus, the members of which are often inclusively termed "plantains" (1) in the Orient. It is closely related to the common banana (*Musa sapientum*) and to the edible plantain (*Musa paradisiaca*). The plant is a tree-like herb growing out of a perennial rootstock to a height of ten to 28 feet, depending upon the variety. Around the edge of the rootstock emerge numerous sucker-shoots which, when mature, convert the plant into a rather large clump of stems and leaves. Cultivated plants cut for fiber usually consist of 12 to 20 stems in various stages of maturity, four to eight of them reaching the mature flowering stage every calendar year. In an old plant the root clump may cover up to 25 square feet of ground.

The single stems are cylindrical, taper upward in diameter and are formed by many overlapping leaf sheaths. A large

stem may measure over a foot in diameter at the base and four to six inches at the top, carrying from six to 14 live leaf blades at the top when nearing maturity. The stem will range from eight to 22 feet in length and will weigh from 50 to about 125 pounds when cut and topped of its leaves. It is mostly green in color but may be irregularly streaked with deep brown, red or purple. The leaves are generally of a uniform deep green on their upper surface, glaucous beneath The leaf blades are oblong and mucronate, three to six feet in length and generally narrower than those of the banana, but exact shape and color differ considerably with the variety. Seen from below, and looking at the underneath side of the base, the abacá leaf has a narrow brown line some two inches from the right-hand edge, and the blade extends down the petiole two to three inches farther on the left side than on the right This detail is opposite the pattern in the common banana. The stalk bearing the flower bud grows upward through the stem in the narrow space surrounded by the overlapping leaf bases after the stem has reached maturity. Flower spikes differ in size with variety, but the blossoms are always borne in prominent clusters subtended by bracts along the rachis of the spike. The flower bud may be cooked and eaten as with many of the bananas (1). The fruit remains green, is oblong and trigonous, generally two to three inches in length and about an inch in diameter. It is inedible and is filled with numerous large black seeds (6). Depending upon the variety, an individual sucker-shoot will reach the flowering stage in 16 to 28 months. After the fruit ripens, the stem deteriorates and dies, if it has not been cut for fiber, and its place is taken by other, newer stems (13)

Dissemination of wild abacá plants seems to have been from the central Philippines southward into Borneo and perhaps also but sparsely to nearby other islands in the Indies. Its southern limit as a wild plant is not well known, and Burkill mentions a wild variety on the island of Amboina, which seems rather far afield (1). Wild plants no longer are common in the central Philippines, but they do occur in some upland interiors of the southern islands and are rather commonly distributed in northern Borneo. The fiber content of wild plants is very low in comparison with that of domesticated plants, and today fiber is almost never gathered from the wild (13).

There now are more than 20 recognized varieties of cultivated abacá, each differing somewhat in fiber characteristics as well as in growth habits (2), and many localized names have been applied to them. Four varieties are dominant in the Philippines today—Tangongon, Bungolanon, Maguindanao, Lauan-Tangongon (2).

In addition, there are regional varieties in certain areas of the Philippines, historically developed to succeed in particular local environments. Besides recognition of these regional varieties, the many types of abacá have often been categorized in other ways. There are several rather short types, usually producing white fibers, often termed " mountain abacá " (5, 6). These are not heavy producers and may be somewhat closer to the wild plant in historic and genetic contact. These are not truly highland or mountain varieties, but today are grown in the more interior upland portions of many islands. An elevation of about 3,000 feet in the southern Philippines seems to be the upper limit of cultivation. The coastal lowland varieties usually are larger. Some of them produce abundant amounts of white, strong, fine fiber, and these are the most highly regarded today. Other varieties yield yellow-toned fibers of lower quality and fineness. One or two varieties, tall slender types, produce smaller quantities of very white but delicate fiber.

The primary physical requirement of abacá is rainfall of even and almost continuous distribution, coupled with high relative humidities (6). Rainless periods of more than a few weeks cause sufficient shortages of soil moisture so that the root systems cannot provide for the heavy transpiration of moisture from the large areas of leaf surface. Such rainless periods prevent full growth of the plant and cause low quality of fiber. Dry periods of only three weeks may be critical for some varieties, whereas others seem able to stand rainless conditions of five to six weeks (2). Periods longer than six weeks without rain lessen the yields of all varieties, and long spells without rain and with low humidities stunt and even kill the plant.

FIG. 1. A young abacá planting made by using young stalks and rootstock cut out of old plants. An older planting occupies the rear ground with forest remnants left as shade provision.

In earlier times when small acreages were the rule, abacá normally was grown in mixed plantings with some shade and protection (11). As plantings increased in the last century, they became individually more extensive with less and less protection from shade trees against sun and wind. Today the protection offered by shade trees has been almost entirely eliminated. Younger plantings suffer most from lowered humidities, and in those areas having short dry spells, young plants need intermittent shade to promote full and rapid growth. Fifty to 70 inches of rain seems to be about the lowest annual total that permits full development, considering all varieties.

On the other hand, abacá does not tolerate waterlogged or over-saturated soils, for it is not a plant of the aquatic fringe. It does not do well on heavy soils of impaired drainage (6). Sandy to loamy soils of considerable depth and

good drainage seem best. It will not tolerate a high water table, nor will it succeed in a soil containing a hardpan shallower than about 30 inches (2). Since it requires long term plantings of many years, it calls for rather rich soils of long run productivity, and prefers neutral soils to those that are strongly acid. In the Philippines many plantings exceed 50 years of continuous cropping, and well drained youthful volcanic soils possessing a long life seem the most productive. There is evidence that some varieties reach a period of peak yield in 12 to 15 years under certain patterns of cultivation, after which their yield declines (2). How much this is a factor of soil depletion and how much is inherent in plant variety is not clear. In clearing new land for abacá planting, forest lands with considerable organic matter seem better than grasslands or older previously cropped soils.

High annual temperatures are another requirement, but few specific data are available to indicate critical minimum values. Altitudinal limits obviously are partly an expression of temperature, but little is known of the specific facts. It has been dryness and windiness instead of coolness which has limited the northward spread of the plant in the Philippines, and the lack of success until very recently in moving the plant to other areas has not given much opportunity to test the role of temperature. Reports that plantings in northern Cuba have not done well may indicate a prohibitive function of temperature, but these failures could be the result also of soil dryness, of low soil quality or of poor planting stock (4).

Continuous or heavy winds inhibit successful cultivation of abacá. Strong winds tear the leaves, hindering growth of the plant, or rip the leaves off entirely and knock down the stems. This factor is most critical in the northern Philippines which lie in the typhoon belt. Every serious typhoon slows down fiber production for 12 to 20 months. It operates to lower annual production in parts of southern Luzon, until recently a chief center of production (16).

Wild abacá originally was a jungle-forest plant, living amidst thick growth which protected it from damaging air movements, excessive solar radiation and drying out of the soil. Its habitat requirements were rather specific and narrow in limits. Early development of the first cultivated varieties produced plants differing in size, date of maturity, color and quality of fiber. This development also produced varieties differing slightly in basic environmental demands. Further development of presently cultivated varieties has perhaps somewhat increased these ranges in quality and environmental demand. However, the basic physiologic requirements of cultivated abacá plants seem not to have been greatly altered from those of the wild varieties, nor have the limits of habitat been notably increased. When cultivated varieties today are mass planted in agricultural landscapes, the purely local environment of the plant is greatly altered from that surrounding the wild plant. Much of its protective cover is then lacking and the plant is subjected to weather elements more than in the wild habitat, making necessary a carefully chosen situation in which its basic demands still can be met.

The modern history of planting efforts demonstrates the attempt to locate and utilize this acceptable local environment. This finally has been successful to a moderate degree, as indicated by present cultivation in a number of countries in both the New and Old Worlds. Little work has been done so far to breed varieties which will succeed in environments with qualities or limits really different from those of the wild plant. When this is done the natural monopoly will be completely broken and wider dissemination of the cultivated plant will be permitted.

In sum, abacá continues to be a plant of the warm and continuously moist tropical lowlands of good drainage and of productive soils. In cultivation it has done best on the volcanic alluvial lowlands of the southern and eastern portions of the Philippines. Middle American environments of basic similarity have been found in which the cultivated plant does well, and a few spots in southeastern Asia have also been found suitable. Historically many factors other than environmental ones apparently have been effective in preventing wide distribution of the plant in southeastern Asia in early and modern times. On present evidence it is difficult to judge how significant have been the strictly environmental habitat factors.

Propagation

Several methods are used in propagating abacá. The cheapest is by planting seed from ripe fruit (6). This has long been used in the past, and selection of good stock from seedlings produced the 20 or more cultivated varieties used at present. The method is rarely employed in the Philippines (2), however, for abacá seed is of low viability and does not produce plants true to the parents (7). Seed is planted in nursery

FIG. 2 (*Upper*). A widely spaced plantation several years old, partially rehabilitated after World War II but not yet of producing caliber.

FIG. 3 (*Lower*). A young planting, rather closely set, from rootstock source, surrounded by more mature plantings typical of the modern clean planted plantations.

gardens and has a germination period of 12 to 30 days. Plants remain in the nursery about a year, at which time they often are about two feet tall. Year-old plants may be set out in the final field locations. Seedling plants take a year longer to reach fiber-producing maturity than do plants grown by vegetative reproduction (6). Experienced planters can weed out some of the undesirable plants during the year in the nursery, but with seed planting there is no assurance that any given number of plants will become good fiber producers.

A more common method used to increase plantings involves utilization of young sucker-shoots which will breed true to the original plant (6). These can be cut from parent plants so as to include a small portion of the rootstock without harming the parent. This is a good method of expanding plantings from approved and established producing stock, and one that is widely pursued in the Philippines today. There is some mortality among sucker-shoots, but losses are not serious. Such plantings reach maturity faster than do seedlings, but since the planted units must develop a root system, this is not the most rapid method of securing harvestable plants.

Another common method of obtaining planting stock is to dig up all or part of the rootstock of a vigorous and productive plant (2). Such a rootstock is then divided into sections, each of which contains one or more growing " eyes " or a partially developed sucker-shoot. More rootstock material can be provided for each new plant by this method than by any other, and plants started from such stock both breed true and mature more rapidly than those propagated in any other way. This method is somewhat more costly, as an initial investment, because it destroys all or part of producing plants.

Field planting of year-old seedling plants, sucker-shoots or rootstock units spreads plants out in rows at distances of eight to 12 feet, with rows generally spaced the same distance apart. Eight-foot spacings permit more plants per acre and give higher initial yields, but in satisfactory local habitats on good soils the wider spacing permits larger development of individual plants and greater long run success (12). Dependent upon the local habitat, young plants may be set in fields with mature shade growth already present in scattered distribution. This method apparently is being followed in British Malaya and in many small plantings in the Philippines (14). In a good habitat plants need little care once they are well established. Weed growth is kept down around the plants for at least three years until the plants can shade their own growing space and prevent serious growth of grasses. Totally clean cultivation is not desirable in the light textured soils best suited to abacá, since it permits increased erosion and does not maintain a supply of organic materials as ground cover. Once plantings have reached mature size and harvesting begins, the plants provide much of their own organic material in the form of topped leaves and the waste portions of stems. After maturity they also shade their own surroundings sufficiently well to restrain much of the weed growth, and require only limited maintenance care. In caring for some of the cultivated varieties, protective pruning of sucker-shoots is practiced to prevent accumulation of too many stems around each plant (2). Some varieties sucker very freely and tend to mature their stems at smaller and less productive size if too many suckers are permitted to grow (2).

For local expansion of abacá plantings in nearby fields, either sucker-shoot or rootstock planting is satisfactory, since the transport problem is not serious. For establishing plantings at a distance, however, there are problems. Rootstock ma-

terial is both bulky and heavy, difficult to move and subject to drying out. It needs some sunshine and cannot be kept covered for too long a period. Sucker-shoot materials are somewhat less bulky but no easier to deal with in transport. Relatively slow and simple water transport facilities, plus the early lack of knowledge concerning the narrow environmental requirements of abacá, probably prohibited any extensive efforts to move live planting stock to many parts of the Orient in pre-Columbian times. At first glance, seed seems by far the better source for plantings to be made at a distance. And thereby apparently hangs much of the story of the historical failure of attempts to establish the plant elsewhere in the moist tropics of the earth. The low viability of seed and the poor productivity of most seedlings have discouraged many attempts to transfer the plant to territories outside the southern Philippines and northern Borneo. There is no good record of how often or how widely this was tried in earlier historic times, nor is there any record of how often it was tried in the first three centuries of occidental contact with the Orient.

FIG. 4. Stalks felled and splits being removed in an old plantation in which plants have spread out to fully shade the ground. Discarded pulp lies to the right and a batch of splits lies behind the splitter.

Plantations Outside the Philippines

Early in the 19th century efforts began to be made to grow abacá in several parts of the world. Some plants were secured from seed in India as early as 1811, but they were not good fiber producers (20). Repeated later efforts were made along the moist eastern coast of India, each trial producing plants, but none of them yielding fiber of good quality at a reasonable price. Seed planted in England's Kew Gardens germinated, and a few plants apparently were moved to the West Indies, but no fiber production resulted (13). By 1900 attempts

had been made to start plantings in the following areas: India, Ceylon, the Andaman Islands in the Bay of Bengal, Sumatra, Java, Celebes, New Guinea, the Solomon Islands in the East Indies, Fiji in the southern Pacific Ocean, Jamaica and Trinidad in the West Indies (4, 7, 13, 18). In every one of these areas a few plants were already growing and in some cases apparently thriving, but in no case was fiber production successful. Failure of seedlings to breed true was not recognized, and thus it could not properly be determined why the plantings did not succeed as fiber producers. Some of the Indian plantings did fairly well, but cleaned fiber cost much more to produce in India than in the Philippines (13). Lacking full knowledge about the plant and its management, the variable roles of climate, soils and good planting stock could not be distinguished in these early trials. Only in British North Borneo had there resulted any success in establishing the plant (13). There native farmers slowly extended small plantings, but it passed unnoticed that such plantings used live rootstock materials rather than seed. In Celebes apparently some local success also was achieved by native farmers.

In the years 1901–1903 interested Americans tried planting abacá seed in Hawaii, Florida, Puerto Rico, Cuba and Trinidad (7). Only the 1903 plantings in Florida and Puerto Rico produced plants, but they eventually disappeared without any record of their performance. In 1911 American interests again tried seed planting and produced a considerable number of plants, some of which found their way to Puerto Rico and to Panama. Nothing happened in the way of commercial planting, but in 1925 some of these plants were re-discovered in Panama doing fairly well, and Puerto Rican plants surviving today probably are derived from the 1911 planting effort.

In 1921 came the first American efforts by government agricultural experts to try introduction of proven live planting stock into Panama, and about the same time Dutch agricultural officials began introduction of live planting stock into Borneo, Sumatra and Java from the Philippines (7, 8, 22). The first American efforts at using live planting stock resulted in a selection of diseased stock, and none of the plants survived long enough to reproduce plants in Panama. The Dutch efforts were a little more successful. British Malayan experiment station officials employed live rootstock experimental planting of several varieties at roughly the same time (14). In August, 1925, a large shipment of live planting stock chosen from six varieties of southern Mindanao abacá was sent to Panama by U. S. Government agriculturists. About a third of the plants in five varieties lived, most of which also proved immune to Panama disease which was then playing havoc with Middle American banana plantings (7). These moves using live planting stock agitated Filipinos who had been unconcerned so long as seed planting had been tried abroad, and in December, 1925, further export of live planting stock was banned (7).

In 1928 in Panama 50 acres of live rootstock materials were set out under four planting systems, using five varieties (7). Sample fiber produced from these plantings proved to be better than the common grades of Philippine abacá fiber, and it appeared that finally it had been learned how to handle the plant in a totally new region. The economic depression of the early 1930's prevented any development of commercial plantings, but in 1936 the topic was revived. Between 1937 and 1939 a little over 2,000 acres were planted in Panama, using the 1928 fifty-acre planting as the source for live rootstock material (7). December 7, 1941, changed the entire picture, so far as American interest and Middle America were concerned, for with the onset of war with Japan, all

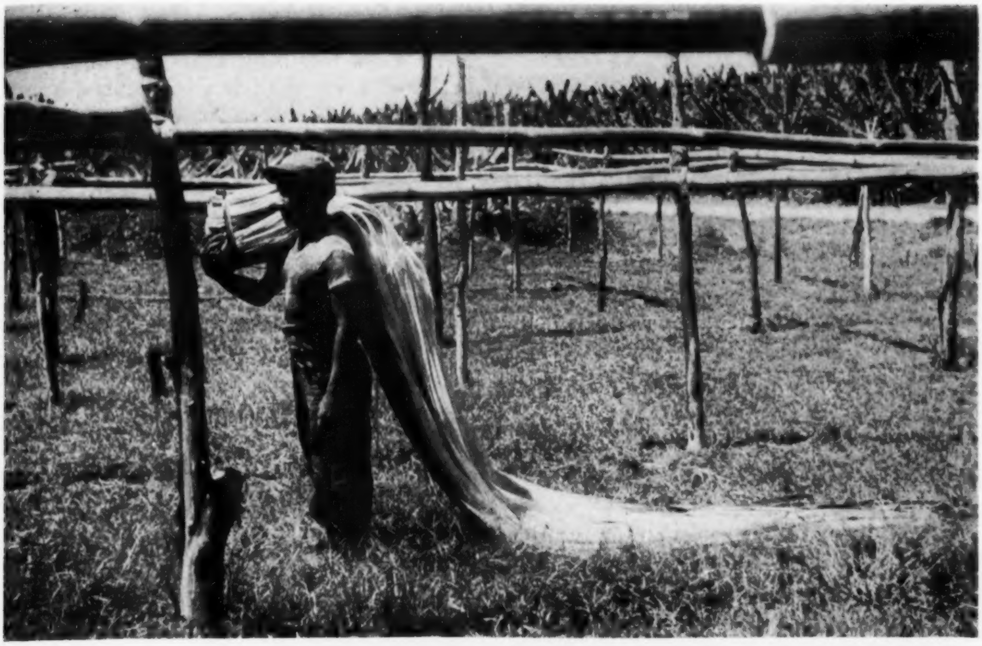

Fig. 5. (*Upper*). The splitter carries convenient-sized batches of splits through the drying yard to the stripping shed.

Fig. 6 (*Lower*). The average Philippine splitting shed is a bamboo and thatch building housing machinery and workmen. Packages of splits are piled near the stripping machines awaiting processing.

Far Eastern sources of abacá fiber became endangered. By 1945 plantings in Middle America had expanded to some 29,000 acres in Panama, Costa Rica, Honduras and Guatemala.

Dutch efforts in the Indies between 1920 and 1941 succeeded in both finding the right local environments on Sumatra for live rootstock plantings and in expanding acreage, though the total acreage never grew sufficiently large to endanger Philippine control of trade markets (17). Malayan efforts succeeded in acclimatizing three standard varieties (14). Japanese interests, which had penetrated the plantation abacá scene in southeastern Mindanao in the decades prior to World War II, also had begun a few ventures in British North Borneo, but these had not become large by the onset of the war.

In these several efforts with live rootstock materials the problems of transporting live plants were solved by modern fast shipping, but the loss of two-thirds of the stock in the early introduction to Panama proved that it still was not a simple matter to ship planting stock long distances. The efforts to find suitable local environments were fairly successful, aided by the experience of modern agricultural science.

In Middle America the United Fruit Company, already skilled in banana culture, was concerned in the experimental planting of live rootstock abacá from the very beginning, this skill making possible the World War II expansion of plantings. Abacá here seems to succeed in some of the same general local environments that are appropriate to the bananas grown by the United Fruit Company, and, in fact, many plantings were made on old banana land, from which bananas had been driven by epidemic plant diseases (12). Though not all the problems of environment and habitat, planting techniques and handling methods have as yet been solved by American, Malayan or Dutch growers it is perhaps fair to say that finally sufficient work has been done with abacá so that further expansion in coming years should be quickly possible in several parts of the world if the effort is made.

Though abacá plants of some kind now grow in India, the Andaman Islands, British Malaya, Sumatra, Java, Borneo, Middle America, Puerto Rico, Ecuador and Brazil, in addition to the home region in the Philippines, only two general regions now possess high quality planting material and now engage in commercial production of the fiber. These two areas are southeastern Asia, meaning the southern Philippines, Malaya and Sumatra, and Middle America, meaning Panama, Costa Rica, Honduras and Guatemala. Experimental work in Brazil and in Ecuador apparently has found appropriate local habitats for abacá, but no commercial plantings there have been recorded (15). At present an American-Ecuador agreement has been reached to facilitate a future 7,000–8,000 acre planting in Ecuador (3). This distribution is the result of well over a century of effort, during which time it appeared that the Philippine monopoly was unbreakable. Finally it has been broken, and economics instead of experimental agriculture will govern what happens in the future.

Diseases and Pests

It could be expected that the abacá plant, as a near relative of the banana, would be subject to most of the diseases afflicting bananas. This is relatively true, but abacá does not seem seriously affected by the common banana diseases that have made plantation growing of bananas extremely difficult. Panama disease, also known as " banana wilt ", has some effect on abacá, but it is less serious than with bananas and seemingly is worse among seedling stock than among healthy plants produced by root-

FIG. 7 (*Upper*). Loose bundles of fiber arriving at the Columbian Rope Company's baling plant in Davao. Fiber is sometimes re-sunned before sorting and grading for the baling machine.

FIG. 8 (*Lower*). Cleaned abacá is sun dried on simple pole racks and then bound in units such as hang under the roof at the left.

stock planting. The abacá plant does not show the full range of symptoms that evidence the disease in banana. Panama disease is caused by a soil-borne fungus, *Fusarium cubense*. Healthy abacá plants have been grown on lands abandoned for bananas in parts of Middle America, but it is perhaps too soon to say that this freedom from the disease will be permanent.

Bunchy top in abacá is a virus disease that causes stunting of the plant and improper grouping of leaves in a small section at the top of the stem (19). In the early 1920's bunchy top disease wiped out all abacá plantings southwest of Manila (2). This region is close to the northern windy margin of the central Philippines, and abacá has not reappeared in that locality as an important crop. Mosaic disease is a rather old disease in the Philippines that also appears to be a virus ailment causing deterioration and death of the plant. During World War II when many plantings were uncared for, particularly the large plantations in southeastern Mindanao, the disease almost got out of hand (16). Early postwar expansion of plantings in Mindanao by farmers not knowing the plant and its ailments used much diseased planting stock and thus spread the disease more widely. In 1951 mobilization of personnel and equipment were making progress at checking the disease, but its widespread dissemination will have repercussions for several years.

Several boring pests injure the stems of abacá in the Philippines. They penetrate as larvae, cutting the fibers and causing discoloration (6, 11). These are old pests that have long caused trouble, but none of them reaches epidemic proportions, and they therefore present minor problems. The pague-pague worm, a caterpillar larva of *Theoses senensis*, attacks abacá leaves and has a tremendous food capacity (2). There normally are three or four generations of these larvae in the calendar year. Occasionally this pest builds up to epidemic proportions in a local region, and by consuming most of the leaves off abacá plantings interrupts the cycle of plant growth and fiber production.

Nomenclature and Characteristics of Abaca Fiber

The names given to many commercial fibers are curious compoundings of error. Manila hemp, for instance, neither is produced in Manila nor is it hemp; the fiber acquired the name as a result of its entering world trade through the port of Manila as a substitute for true hemp, the fiber of *Cannabis sativa,* and the historical error has probably become too strongly entrenched in the literature and terminology of commercial trade ever to be changed. Though "abacá" is the best specific name for the fiber, native Philippine usage in the past has applied several special terms to particular grades of the fiber.[1]

Abacá is the strongest of commercial plant fibers, about three times as strong as cotton, twice as strong as most of the sisals, and somewhat stronger than true hemp (4). Its strength is very great longitudinally, but transversely it is weak (21). In common with most other tropical fibers it is classed as a hard fiber, in distinction to the soft fibers of the sub-tropical and mid-latitude regions, but this is a very arbitrary matter (4). The fiber of *Musa textilis* is less lignified than is that of other species of *Musa,* a feature which accounts for the relatively light weight of the former. The fiber strands, as they are extracted, are three to 12 feet in length, 1/500 to 6/500 inch in diameter, and each strand is composed

1 Accepted American procedure places an accent on the last syllable of the word abacá, but this is not universal in the Philippines, where often the accent is on the first syllable. In pronunciation, regardless of the syllable stressed, the letter "a" has a soft sound in all cases.

FIG. 9 (*Upper*). Forest being felled for expansion of plantation abacá. The young plants will be set out amid the rubble which will soon rot into the soil.

FIG. 10 (*Lower*). International Harvester Company's Philippine plantation is mechanized similar to the new Middle American plantations. Stalks are halved and removed to a central processing plant.

of up to 15,000 or perhaps 20,000 fiber cells. The strands reveal five to 40 cells in cross section when viewed under a microscope, each of which cells may be up to four-tenths of an inch in length and 12/10,000 inch in diameter (21). The fibers attain maximum development within the leaf sheaths as the stems reach maturity and the flower buds emerge. At the same time new stems in various stages of growth have arisen on the perennial rootstocks, and the mature stems may be removed without harming the plants.

Harvesting and Preparation

Cutting of stems for fiber is done during the interval between emergence of the flower bud and ripening of the fruit, for after this, deterioration of the stem sets in and the fiber loses its high quality. Cutting plantations four times per year seems most practical, for in this way fairly continuous work patterns may be maintained and a continuous flow of good quality fiber obtained. Stems are cut a few inches above the rootstock, on a slant to prevent accumulation of water on the cut surface which would otherwise result in rotting of the plant tissue. Stems being both bulky and heavy, normal Philippine practice is to top the stem and to remove those portions of each leaf sheath containing the fiber close to the spot where each stem is cut. This both saves labor in transport and provides organic material for replenishment of the soil (16).

Each mature stem contains from ten to 20 useable leaf sheaths, from which high quality fiber may be obtained. The thicker the sheath the more fiber it contains. From the central outer portion of each sheath three or four strips of fleshy material are removed, for this is the portion containing the important structural fibers. This is done by hand, on the ground, using a large knife to start each section, after which an expert flip of the hand loosens the long strip (16). Every strip, termed "tuxy" or "split", contains excess pulpy material which is later removed in cleaning the fiber. Each sheath contains a variety of fibers. The outer strands usually are coarser and heavier than the inner ones, and normally darker. The outer older sheaths also contain coarser darker fibers than do the inner sheaths. The innermost sheaths of the stem, and the flower spike, do not produce good fiber and are seldom stripped.

The "splits" from several stems are carried to a central point where the stripping, or cleaning, is done. Cleaning must be performed within 48 hours after cutting the stem lest fiber quality be reduced (21). Many methods have been employed. The traditional Filipino procedure of the past was to use a simple scraping process, several modifications of which have been developed, involving slightly different equipment and different cleaning motions. In a common version a hard wooden block is fastened to a log, and a heavy section of bamboo or a heavy knife blade is suspended above the block (16). By use of a foot-treadle the blade is pulled down against the block with considerable pressure. A group of fiber strands is drawn by hand across the block under the blade, removing the pulpy material clinging to the strands. Common grades of fiber are drawn through the cleaning apparatus only once, but high grade fiber normally will be cleaned two or three times. After cleaning, the fiber is hung on racks in the sun to bleach and dry, a process which may take from four hours to two days, depending upon the constancy and heat of the sun. Good fiber well cleaned by this simple process will be of high quality. After air drying, the fiber may be used directly in the manufacture of many kinds of articles, from simple binding strings to fishing nets, ropes and textiles, or it may be packaged and transported to a point of sale.

Current practice in some parts of the

Philippines where abacá is an important crop is to use simple power machinery for the stripping process. A motor driven wheel is placed behind a steel cleaning blade which can be held to a steel bar. By wrapping one end of a bunch of "splits" around the wheel hub, mechanical power pulls them across the bar under uniform pressure of the cleaning blade (16). Hand equipment very seldom permits more than 30 pounds of clean fiber per man day, and is punishing labor. Hand operators seldom work every day at fiber cleaning. The simple powered machine will clean up to 600 pounds per man day. One stripping machine per 25 acres, operating all year, seems a feasible distribution.

An alternative method of cleaning, or "decorticating", the fiber is used on a few large plantations, both in the Philippines and elsewhere, and the fiber produced this way in the Philippines is called "deco" fiber (16). In the field mature stems are cut into sections about four feet long and transported whole to a central plant by powered transport equipment. In a series of machines, in one continuous operation, the stems are crushed and put through a stripping apparatus, and the fiber is washed, beaten and dried by artificial heat. Up to 1,000 pounds of fiber per hour can be turned out this way. Such mechanically cleaned fiber is as strong as that cleaned by simpler methods, but sun dried fiber has a better luster and appearance than mechanically cleaned fiber and ranks higher in quality grading. Hand "splitting" and simple stripping techniques seldom harvest more than half the usable fiber in a stem, whereas mechanical decortication extracts almost all the usable fiber. In the latter process the yield ranges from about 3.25 to 4.10 percent of the weight of the stem, dependent upon plant variety. Mechanical decortication normally flushes the pulp of the stems into a stream, rather than leaving it on the fields to rot into the soil. This requires that other than standard soil maintenance practices be developed for those plantations using the process.

In the Philippines abacá fiber designed for export is graded very carefully, and a government bureau, the Fiber Inspection Service, maintains a constant check upon the classified sortings of some 30 grades of fiber. Most export fiber falls into about 12 grades. Elsewhere this elaborate system of grading export fiber has not yet developed to an equivalent extent.

Utilization

Abacá is the world's foremost cordage fiber, especially for marine usage where its resistance to salt water is particularly significant. Such utilization in rope and marine hawsers throughout the world has developed since it first came into local use among Boston and Salem shipping men during the 1820's.

Manufacture of fishing nets from Manila hemp is an old application of the fiber in the Orient, and traditional Filipino practice has employed it in clothing despite its hardness. For inexpensive clothing textile, carrying cloths and similar uses the inner fine strands of fiber have long been knotted together and used directly instead of being spun into composite thread as is done with the short textile fibers. For finer grades of textiles the clean fiber was pounded in a wooden mortar to give it a soft and elastic quality, obviously a later gradual development. Fine grades of fiber could thus be made into excellent quality textiles. In a warm and humid climate a good clothing textile need not be soft, fuzzy and warm. As late as 1910 looms for the making of abacá textiles were to be found in almost every town in the islands, but the decline in their use has been so steady and finally almost complete that today the traditional native textiles are made in only a few local regions in relatively small quantity.

Though most of the world's abacá pro-

duction currently goes into export, a large volume is still used in the Philippines. Fishing nets, strings, ropes and carrying cloths are locally manufactured products. And to compensate for the traditional clothing textiles, there is today an increasing use of abacá in making table linens, hats, purses, bags, slippers, mats, rugs and similar products of Filipino artistic handicraft for the domestic and export trades. Japan has used abacá in the making of heavy papers for the construction of moveable walls in domestic housing (4). In the northern United States, during the Civil War, when fibers were in short supply, old Manila hemp ropes and hawsers were converted into strong brown papers. This is the origin of our common terms " Manila folder " and " Manila envelope ", even though those items are not often made of abacá today. Various European applications of abacá in paper products have been made in the last several decades. In the United States today there is increasing use of abacá from old rope, waste fiber and lower grade fibers in making a variety of grades of paper, ranging from strong white tissue to strong and heavy sacking for flour, lime, cement and similar products. Within the near future, as the world volume of abacá increases, many additional uses beyond " Manila rope " will doubtless be found for this excellent fiber.

Patterns of Production and Trade

The whole early history of abacá fiber production is, of course, related to the southern Philippines and northern Borneo. It began with the gathering of fiber from wild plants for some of the simple uses to which an early culture group would put a textile fiber. The technique applied to the *Musa* genus undoubtedly originated with others of the genus elsewhere than the Philippines. Possibly *Musa malaccensis* or *Musa violascens* were the wild species used first in southeastern Asia (1). Knowledge gained with bananas made work with abacá easier, and domestication of some of the bananas outside the Philippines probably preceded work with abacá in its homeland. Early man must have quickly realized that *Musa textilis* was a better fiber plant than others of the genus. When domestication of *Musa textilis* took place is hard to say, but, since the conscious manipulation of plants and crop growing was introduced into the islands by immigrant populations from the western Indies and the southern mainland of Asia, abacá could hardly have been one of the first crops to undergo domestication. Domestication of it, however, clearly took place first in the southern Philippines, not in Borneo, and long enough ago that there are marked differences between wild plants and domesticated derivatives.

By the archaeologic record the earliest cultures occupying the Philippines employed bark pounding techniques for the manufacture of bark cloth. Whether or not they also used fibers of any *Musa* species is not yet determined. But at some date fiber-made cloth began to replace bark cloth, and in the course of time abacá textiles totally replaced bark cloth in the islands, unlike the long continued use of bark cloth by the more southern Indonesian cultures. This substitution of abacá for bark cloth took place well before the invasion of occidental cultures. Abacá was well developed, in both cultivation and fiber usage, when the Spanish came into the islands in the 16th century, though there is a little evidence that among some of the island culture groups the common textile product was not then very high in quality. Upon the arrival of the Spanish there existed a considerable trade in abacá fiber, Chinese traders purchasing it for shipment to southern China and small volumes moving to other parts of mainland and island southeastern Asia.

There are naturally no statistics for that trade, nor is any estimate possible for the distribution of cultivation within the islands.

During the Spanish period, as population grew and the demand for native textiles increased, abacá was one of the crops that markedly expanded in the general increase of agriculture within the islands. Late in the 18th century the Spanish required extension of abacá plantings by native farmers. The eastern regions of the central Philippines gradually came to be the chief area of abacá production. These eastern regions offered better local environments than other parts of the central or northern Philippines because they are moist, do not suffer from long dry periods and are not subject to frequent heavy winds. The southern and eastern parts of the island of Mindanao never came under Spanish control, remained lightly populated and were not important in agricultural production during the Spanish period. Plantings of abacá spread northward into the edges of the severe typhoon country and throughout the central Philippines wherever local environments were suitable. As population increases gave an added market and as Chinese trade increased, so did abacá production increase. With increased production possibly there resulted the development of some of the cultivated varieties, and certainly skill in handling the plants improved along with advances in preparing the fiber and the textile. It was only in the American period that southeastern Mindanao began production of abacá, gradually increasing in importance in recent decades.

The first appearance of abacá fiber in the United States resulted from a shipment to Boston in 1818. Shipments to New England ports were repeated in succeeding years, and abacá began to catch on as a fiber for the making of marine ropes and hawsers. By 1840 the fiber had become generally popular among occidental shipping circles. Philippine exports reached 30,000 tons in 1860 and continued to increase to 89,438 tons in 1900, becoming a significant item in international trade. The Philippines began to profit from possession of a significant agricultural trade monopoly. In 1900 the export of abacá was scattered among many countries the world over, since the Spanish had finally permitted free trade in the islands and the United States had not yet begun to monopolize the Philippine import and export trade.

Under American control commercial agriculture made great strides in the Philippines, using a variety of crops. Large scale plantings of abacá began to appear in Mindanao, one of the few possible regional environments suitable to abacá where land holdings could be obtained. Within the Philippines, in the last half century, there has been a steady increase of large plantings, until abacá from plantations and large farms in southeastern Mindanao regularly makes up half the total Philippine production (16). Gradual decline of the native abacá textile industry has accompanied this change so that today the crop is chiefly one destined for the international market. As this market has grown, the efforts to break the Philippine monopoly have also grown, to the ends previously indicated.

Trial samples of abacá had been produced from plantings in many countries at irregular dates between 1860 and 1930. During the 1930's small amounts of commercial fiber began to be exported from the Netherlands Indies. In 1939 the first commercial product from Middle American plantings appeared, a good quality fiber that moved exclusively to the United States market. The United States imports of abacá fiber in 1940 included 2,053 tons from the Netherlands Indies, 57 tons from Panama and five tons from British Malaya (10). Im-

ports in 1941 were the highest on record, with a total of 111,167 tons. Of this, 109,211 came from the Philippines, 1946 tons from the Netherlands Indies and ten tons from Panama.

In the patterns of trade in the last two decades, the United States has taken approximately half the world production of abacá. Japan ranked second as a consumer of the fiber, taking about one-fifth of world production in the prewar period, but has not yet resumed large volume purchases (9). Great Britain normally ranked third as an importer, but its early postwar imports were small in comparison with prewar volumes, and only in 1950 did large volume imports begin to occur. Other countries that have been steady buyers of important amounts of abacá fiber are Canada, France, Germany, Denmark, Netherlands, Belgium and Norway. Soviet Russia was a small importer in prewar years but is not now a direct importer of importance (9).

With the onset of World War II production of abacá in Middle America began in earnest, to prevent a strategic shortage. By the end of the war Middle American plantings, under government stimulation, had grown into a significant total, and the annual production began to constitute a competitive trade item to the Philippine monopoly. Philippine plantings suffered badly from neglect during the war, and also in the immediate postwar years, through confiscation and break-up of the Japanese plantation holdings in southeastern Mindanao. Philippine production dropped almost to half its prewar average, but currently it is actively increasing and is almost back to its prewar level (16).

Data for 1949 indicate these commercial producers: Philippines, 72,600 tons; Panama, Costa Rica, Honduras and Guatemala under United Fruit Company management as a single operation, 16,000 tons; British North Borneo, 1,000 tons; Indonesia, possibly 1,800 tons, though abacá and sisal are now tabulated together as hard fibers (9). It should be noted here that Philippine production for 1949 still showed the effect of postwar fluctuations and that 1951 production was restored to about 150,000 tons, the highest postwar total so far. Total abacá balings for export in 1951 amounted to 138,815 tons, but fiber for domestic usage seldom is baled and is not reflected in baling figures.

Total acreage devoted to abacá among the commercial producers of fibers amounts to about 755,000 acres today. The Philippines lead, with approximately 720,000 acres in 1951. British North Borneo and the Republic of Indonesia account for about 2,500 and 3,600 acres, respectively. Prewar acreage for Indonesia was in the neighborhood of 13,000 acres on Sumatra and Java, but currently only a small share of the Sumatra acreage remains in production (10). Malayan acreage so far amounts to only a few small plantation plots of perhaps 40 acres in total. Middle American acreage totals just over 29,000, Costa Rica leading with 12,170; Panama, 6,000; Guatemala, 5,800; and Honduras, 5,100 (15). Wartime plans aimed at higher total planting than was achieved, and long range strategic planning by the Reconstruction Finance Corporation under the Abacá Production Act (Public Law 683, 1950) still aims at approximately 40,000 acres of abacá plantings in Middle America and northern South America to assure strategic stock piling.

It is significant that overall production for the Philippines averaged not far from 400 pounds per acre in 1951. Southeastern Mindanao plantation averages have been close to 1,300 pounds of fiber per acre, so that some small farmer averages are quite low indeed. Costa Rican plantation averages per acre in 1949 were 1,140 pounds, but some field units averaged over 1,500 pounds of fiber per

acre. This would indicate that modern scientific handling of this old textile fiber plant has markedly increased its per acre productivity. In part this is a question of better agricultural production techniques on large land holdings, but also one factor is the greater efficiency being achieved in the reclaiming of fiber from the plant on the plantations which use mechanical separation processes. These processes are only partly used in southeastern Mindanao, whereas all Middle American, Indonesian and Malayan fiber is mechanically decorticated. A factor of economic significance in Middle America is the lower overhead costs of growing abacá on old banana lands or on sites nearby in which the existing equipment and facilities of the United Fruit Company can be used in abacá production. Labor costs and other intangible factors may offset this initial advantage over a period of years. These several factors are but straws in the wind with regard to the future of the crop in Philippine commercial agriculture. There is partial recognition of this fact in a recent Philippine Government special sanction of one 18,000-acre corporate abacá plantation in southeastern Mindanao. Filipino small-farmer productivity per acre never has been high, and in abacá production it is dropping behind. The Philippines are desirous of maintaining control over the world market in their native product. Though island land policy is against large holdings and the plantation system, Filipinos must improve their farming techniques on small farms, turn to scientific plantation techniques or gradually lose their control over the production of and international trade in abacá fiber.

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The Cultivated Capsicum Peppers

Chilis in Latin American cooking, pimento in stuffed olives, paprika, cayenne pepper, bland bull-nosed peppers stuffed with meat, and the very pungent African chilies are all varieties of Capsicum peppers.

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Although Columbus never reached the Far East, he did manage to obtain a plant that has since come to rival the spices of Asia. In 1493 Peter Martyr (1) recorded that Columbus found that the natives of the new world had certain plants more pungent than the pepper of the Caucasus. These plants were later named *Capsicum* by the herbalists, and this name was adopted for the plants by Tournefort and subsequently by Linnaeus. The common name "pepper", however, has stuck with them, although true peppers, the black and white peppers of commerce, come from an unrelated plant, *Piper nigrum*, of the oriental tropics. To distinguish them from the true pepper, they are called "chili" (also spelled "chile", "chilli"—from an Indian name of the plant) in various parts of the world, but this name has never received wide usage for the cultivated capsicums in the United States.

History

Prehistoric peppers are known from the burial site at Ancon, Peru (30, 31), and from Huaca Prieta, Peru (4). From the accounts of the early explorers of tropical America and the later ethnologists, it is known that peppers were widely cultivated in the New World and constituted an important item in the diet of the native peoples. According to Humboldt (17), the peppers were "as indispensably necessary to the natives as salt to the whites". After the discovery of America the peppers spread widely throughout the world and were soon well known in Europe.

The first peppers to reach Europe were of the pungent sorts, although sweet varieties were already in existence. Acosta (2) mentions one sort from the West Indies that was "not so sharpe, but is sweete, as they eate it alone as any other fruit". Piso (according to Sturtevant, 13) also mentions a non-pungent form. Many of the peppers were grown for the ornamental value of the fruits and apparently were much less esteemed for other uses at first, although in due time the herbalists listed many "medicinal" properties. It seems likely that the first peppers cultivated in the United States came directly from Europe instead of from Central and South America, although Hedrick (14) does not list them among the early horticultural products of New England. Sturtevant (13) states that the pepper was in cultivation in the United States before 1828.

Uses

Peppers are employed both as a food and as a condiment. In this country

FIG. 1. Inspecting chili peppers (*C. annuum*) at the Gentry plant in Oxnard, California. (*Courtesy Gentry Division, Consolidated Grocers Corp.*)

the large thick-fleshed sweet or non-pungent varieties are widely used in salads or are stuffed with meat and cooked. Their chief nutritional value lies in their high vitamin C content—the ripe fruit has 150–180 mg./100 gm. green weight which is higher than found in tomatoes (20–25 mg.). The red ripe fruit of a sweet thick-fleshed variety, used in considerable quantity in cheese, stuffed olives, processed meats and for cooking, is known as " pimiento " or " pimento " (not to be confused with *Pimenta officinalis,* or allspice, which is sometimes

called "pimienta"). Paprika, cayenne pepper and chili powder all come from the dried, ground, ripe fruit of *Capsicum*. Paprika, a non-pungent type, most of which is imported from Spain, is used largely for garnish and sometimes for coloring. Cayenne or "red pepper" is moderately pungent and is best known as a household seasoning. Chili powder is a mixture of ground chili pepper and several other flavorings which usually include oregano, cumin, garlic or onion, salt and sometimes other spices. This is widely used in chili con carne, and often in stews, beans, sausage and bologna, in various sauces for meats and in the home for seasoning. The small pickled peppers are made from the yellow immature fruit of the Floral Gem and Hungarian Yellow Wax varieties.

People of Latin American extraction, particularly in the Southwest, use considerable quantities of fresh and canned green pods of a long slender Anaheim (California) chili as well as the dried pods of this variety in their cooking.

Although peppers have become fairly important in many areas of the world, their greatest use is still in their native home. Bukasov (6) has written that in Central America all types of food—soups, sauces, vegetables, omelets, meats, pancakes—are seasoned with amounts of pepper which would be quite unacceptable to Europeans. It is a common observation, often very unpleasant to the uninitiated, that large amounts of highly pungent peppers are used directly and as flavoring for their foods by the native peoples of Central America and parts of South America. The use of peppers in chili has recently been the subject of a book, "With or Without Beans," edited by Joe E. Cooper. At one time Capsicum had a fairly important role in medicine, and it is still so used to some extent today. The African chilies are among the most pungent known, and are the ones most commonly used in pharmacy. The dried fruit may be prepared in a number of ways for use as an irritant for rheumatism or neuritis, as a gargle for certain throat inflammations, or internally for alcoholic gastritis and certain types of diarrhea (26).

The florist trade makes use of a dwarf small-fruited form, particularly as a winter ornamental. The bright red and yellowish-white fruits are borne in profusion and make it an attractive house plant. This is a true form of *Capsicum annuum* and should not be confused with the Jerusalem cherry (*Solanum pseudocapsicum*), a fairly common door-yard ornamental.

Capsaicin Content

The pungent principle of peppers, capsaicin ($C_{18}H_{27}NO_3$), is a volatile phenolic compound related to vanillin in structure. It is quite stable, persisting in apparently unreduced potency in pepper pods for considerable periods of time. It is extremely potent, and the pure form, according to Nelson (23), can be detected by taste in a dilution of one part in one million.

Various methods have been devised to measure quantitatively the amount of capsaicin in pepper pods. The method recently described by North (24), while accurate, is quite laborious. The older tests, based on the fluorescence of capsaicin or its color reaction with vanadium oxytrichloride are not accurate. At the present time the commercial producers of pungent pepper products rely upon the organoleptic test. This involves dilution of pepper powder or an alcohol extract with tomato juice, sugar solution or similar material. The relative pungency is then expressed in the amount of dilution required to reach about the threshhold of taste. The pungency to reach the end point of taste may vary in pepper varieties from dilution of 1–1000 to 1–50,000 or more by weight.

Capsaicin is found in placental tissue only and is controlled by a single dominant genetic factor. The seeds and ovary wall of the fruit (a berry) are non-pungent, in spite of popular belief to the contrary. The degree of pungency between varieties varies extremely, probably due to the presence of genes modifying the factor for pungency and to the ratio of placental tissue to seed and pod wall.

FIG. 2. Drying chili peppers at the Gentry plant in Oxnard, California. (*Courtesy Gentry Division, Consolidated Grocers Corp.*)

Production in the United States

According to statistics released by the Bureau of Agricultural Statistics of the United States Department of Agriculture, the green pepper crop for the fresh market in 1951 was valued at $16,839,000, and a total of 105,600 tons was produced on 34,700 acres. The leading States in the production of green peppers were Florida, which is the chief producer during the winter and spring months, New Jersey, North Carolina, Texas and California. Pimiento production is confined almost entirely to Georgia where 32,000 acres, valued at $3,150,000, was reported in 1950.

Tabasco production is confined mainly to southern Louisiana, and scattered acreages of Cayenne pepper are grown through the southern United States. Production is so limited that no crop statistics are available.

Chili peppers are grown in California and to a very limited extent in Arizona.

FIG. 3. Workers picking Tabasco peppers (*C. frutescens*) at Avery Island, Louisiana. (*Courtesy Standard Oil Company of New Jersey, Webb photo*).

In 1950 California reported a production of 3,850 tons of dry red chili from 3,932 acres, worth approximately $3,000,000. This does not include considerable quantities of these same chilies picked green for the fresh market and canning.

Nearly all the paprika used in the United States is imported, mostly from Spain, the 1950 import amounting to 3,500 tons. Most of the highly pungent peppers for " red pepper " and pharmaceutical use are also imported. In 1950, 2,700 tons were imported, about half from Mexico, and the bulk of the remainder from Japan and Africa.

Taxonomy

Capsicum is a genus of the Solanaceae closely related to *Solanum*. All species of the genus except one, *C. anomalum* of Japan, are native to the New World.

At the present time it is difficult even to estimate the total number of species in the genus. More than 100 binomials

have been proposed, many of them for cultivated forms. In all probability many of the binomials should be referred to one or the other of the two cultivated species, *C. annuum* and *C. frutescens,* although it will be difficult to place satisfactorily many of the early " species " because of brief or incomplete descriptions. Many of these " species " were based primarily on fruit shape, size, color and position which have been shown by recent workers to be quite variable and hence rather unreliable for specific determinations. The recent work of Smith and Heiser (36) has shown that flower characteristics provide quite consistent characters for taxonomic identification.

The genus as a whole has never received anything approaching monographic treatment since the time of Fingerhuth (10), and there are few modern studies dealing with the wild species of the genus. Hunziker (18) has recently given a rather full treatment to the species of Argentina and Bolivia. More such studies are urgently needed for other parts of South America. Sendtner's (33) treatment of the Brazilian species is now over 100 years old.

The cultivated peppers have received somewhat more attention. In a very comprehensive study, Irish (19) recognized two species, *C. annuum* and *C. frutescens,* the former with seven botanical varieties, including 42 named " horticultural varieties " or forms. His classification was rather widely adopted and is still followed by most European and Asiatic botanists. Bailey (3), however, concluded that there is only a single cultivated species and that, since all peppers are perennial in their native habitats, the name *C. frutescens* should be used in preference to *C. annuum,* although the latter was first of the two names proposed by Linnaeus; Bailey could not allow " the incident of precedence on pages to obscure a biological fact ". Bailey's treatment has been accepted by Erwin (8) who made many contributions to our knowledge of garden peppers in this country and who has also been followed by most plant breeders and horticulturists in the United States. This state of affairs has led to the rather anomalous situation of the same cultivated plant being called *C. annuum* in some regions and *C. frutescens* in others. Smith and Heiser (36) have recently recognized both *C. annuum* and *C. frutescens* as valid species, although their specific lines are slightly different from those proposed by Irish. Their conclusions are based on the lack of crossability between the two groups of peppers, and slight but distinct morphological differences. The majority of the peppers of commerce at the present time are forms of one or the other of these species. Two other species, *C. pubescens* and *C. pendulum,* which are known from Latin America and are definitely cultivated, have only recently become fairly well known. Certain other of the cultivated forms of pepper now being studied have not been placed definitely in any one of these four species as yet and may eventually prove to be distinct (Smith, unpubl.).

The four cultivated species now recognized may be keyed as follows:

Corolla lobes purple; seed black; leaves rugose; stem and leaves rather densely pubescent
1. *C. pubescens*

Corolla lobes white or greenish-white, rarely purple; seeds light in color; leaves smooth; plants glabrous or pubescent

- Corollas white with yellow or tan markings on throat; anthers yellow ... 2. *C. pendulum*
- Corollas without yellow markings on throat; anthers light blue to purple
  - Corollas greenish-white (or yellowish white); pedicels solitary or more frequently paired, or several at a node
    3. *C. frutescens*
  - Corollas clear white or dingy white, rarely purple; pedicels solitary, rarely two at a node .... 4. *C. annuum*

1. *Capsicum pubescens* R. & P., or "rocoto" as it is commonly called in South America, was originally described from Peru in 1790 and in more recent times was reported from Colombia (6), Mexico, Guatemala and Honduras (15 [1]). Its uses, variation and distribution in Peru have recently become known through the work of Rick (29). In 1949 Erwin (9) reported a pepper from Guatemala which he referred to *C. guatemalense* Bitter. From his clear descriptions and photographs there is little doubt that it is the same as *C. pubescens*.

Capsicum pubescens is the most easily recognized of the cultivated peppers. The dark, usually much wrinkled and curved seeds, the purple lobes of the corolla, the folding between the lobes of the corolla, the overall pubescence of the plants, and the very rough leaves readily set it apart from the other peppers. The fruits are variable in size and from mildly to strongly pungent. In the material so far observed by the authors, only the green immature color has been seen, but the ripe fruit color ranges from red through orange to brown.

Whether this species exists in the wild state is not known. It was originally described from cultivated material, and Rick, in his travels in Peru and Ecuador, did not observe it in the wild. Erwin, in his account of the pepper in Guatemala, states that "it is native to the region". Several herbarium collections from Guatemala by Standley and Steyermark (15) are all from cultivated plants or "escapes" (Steyermark, in litt.). At present the greatest diversity of forms appears to occur in the Andes. The information available at present indicates that this species is limited to relatively high elevations and is uncommon in or absent from the lowlands.

All forms of this plant which have been cultivated in this country are very late in maturing, and at present it seems to offer little of horticultural value in the United States for this reason.

2. *Capsicum pendulum* Willd. is rather widely distributed in South America, having been collected in Argentina, Bolivia, Brazil, Chile, Ecuador and Peru, but thus far is unknown for Central America. One collection was obtained from Hawaii, where it had been cultivated for some time and where it was undoubtedly an introduction. In coastal Peru it is one of the most popular of the cultivated peppers, but in spite of its rather extensive use and popularity there is apparently no mention of it in the literature previous to 1951 (37). The original description apparently was based on material cultivated in Europe, and there is still some doubt that the brief description given by Willdenow actually applies to this species.

The most distinctive feature of it again lies in the flower. The tan or greenish-yellow areas, dissected by the network of veins, on the corolla and the yellow anthers readily distinguish it from the other cultivated species known at present. These same floral characteristics are found in two wild species, *C. microcarpum* Cav. and *C. Schottianum* Sendt., which are fairly widespread in South America (18). Whether *C. pendulum* occurs in the wild state is not known, but it does not seem unlikely that *C. pendulum* may prove to be simply a cultivated form of one or the other of these wild species. A study of the genetic relationship of *C. pendulum* to *C. microcarpum* is underway at present.

Without examining flower color, it would be easy to confuse *C. pendulum* with either *C. annuum* or *C. frutescens*, and it seems likely that this species may have been masquerading for a long time

[1] Two additional localities in Mexico have become known for this species since publication of the above paper. Dr. Carl O. Sauer collected seeds of this species in Tlatlauquitepec, Vera Cruz, and fruits purchased in a market in Xochimilco, D. F. were sent to the authors by Dr. Isabel Kelly.

under one or the other of these species names. Although herbarium material is frequently rather unsatisfactory in this genus, a careful study of the specimens in the herbaria of America and Europe might turn up additional records of this species.

Although *C. pendulum* is not known in cultivation in the United States at the present time, it may eventually prove of some economic importance here. Unlike *C. pubescens* it matures early and bears profusely in preliminary tests in this country. Its usefulness in plant breed-

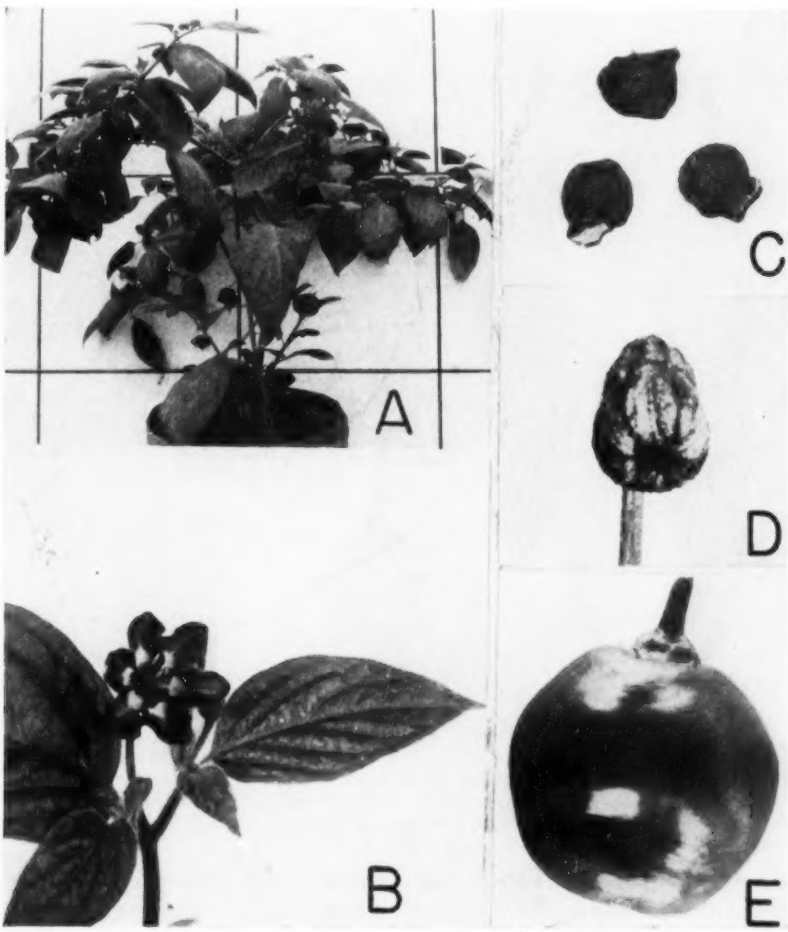

FIG. 4. *Capsicum pubescens*. A. plant, B. flower, C. seeds, D. flower bud, E. fruit.

As with the other cultivated peppers, fruit size and shape are quite variable. Immature fruit colors vary from almost ivory white to yellow or green, and the mature fruit from orange yellow to red. The brown colored fruit has not been observed.

ing with the species now under cultivation may be limited by the high sterility obtained in species crosses, however (see below).

3. *Capsicum frutescens* L. is widely cultivated in tropical and subtropical regions of the world today. It is currently

found in the native agriculture of Mexico, Central America and South America. It was early noted on certain of the Pacic Islands by Pickering (28) and others, but whether its introduction into the islands was post- or pre-Columbian has not been definitely ascertained. Only one variety, Tabasco, is grown to any extent in the United States. This variety is the source of the well known and widely used Tabasco sauce. Part of the "African" chilies for pharmaceutical use belong to this species.

The greenish-white or yellowish-white corollas and the frequently multiple pedicels are the most distinctive morphological features. Fruit size and shape are rather variable, but no fruits have been seen which exceed ten cm. in length, and therefore they do not reach the large size of *C. annuum*. In general, forms of *C. frutescens* are fairly late in reaching maturity.

The very small fruited peppers frequently called "bird peppers" which are considered a variety of *C. frutescens* by some and by others a distinct species, *C. baccatum*, are naturalized in many regions. According to the little genetic work that has been done on them, some of the small fruited forms fall within the limits of *C. frutescens*, others within *C. annuum*, while others are still in doubt and may represent distinct species. They are found in Arizona, New Mexico, Texas and Florida in the United States, and in both Central and South America, and India. Whether these forms represent escapes from cultivation and "reversions" to a wild type or whether any of them are truly native wild types in certain areas is not yet known.

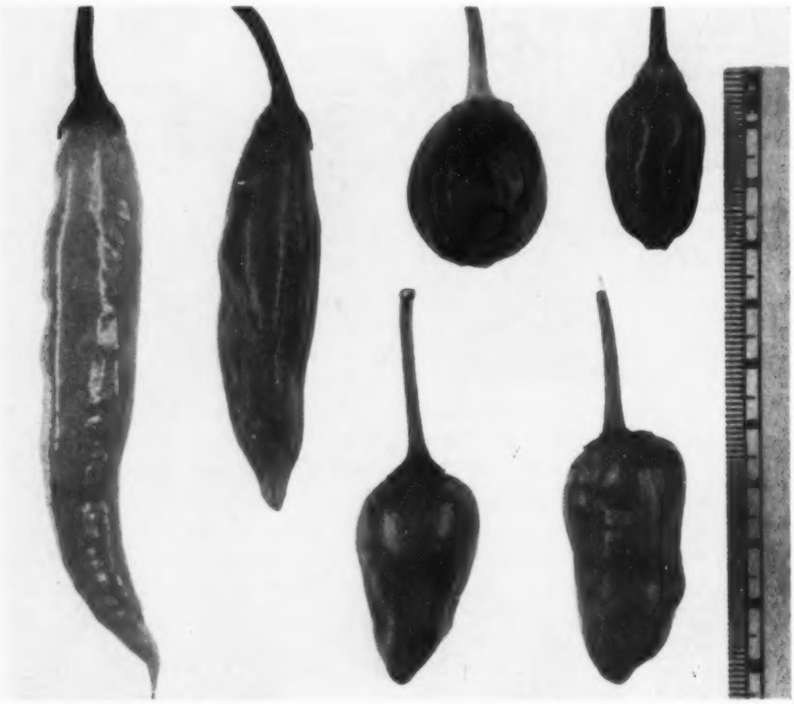

FIG. 5. Variation in shape and size of fruits of *Capsicum pendulum*.

4. *Capsicum annuum* L. includes a vast number of horticultural varieties and is by far the most important pepper economically. Because of its adoption as a food plant and its spread throughout much of America in recent times, it may be difficult to delimit its pre-Columbian distribution. Bukasov (6) reports that the centers of diversity for this species are in Mexico and Brazil. There can be no doubt of the correctness of considering Mexico a center of diversity, but some question remains in regard to Brazil, for Bukasov did not recognize the existence of *C. pendulum*. Rick, in his travels in northwestern South America, did not observe *C. annuum*, and it is not listed among the wild peppers of Argentina and Paraguay by Hunziker (18).

Fruit shape, size and color are extremely variable in this species, more so than in any other. The fruit varies from about 1 cm. to 30 cm. in length, from small conical to thick-fleshed blocky or flattened. Both the yellow and green immature color, and red, yellow and brown mature fruit colors are common. Vegetative characters, likewise, vary greatly.

Virtually all the larger fruited varieties now grown in the temperate zones of the world belong to *C. annuum*. With the exception of Tabasco, all the principal commercial varieties in the United States belong to this species. The short growing season required and the occurrence of non-pungent as well as pungent forms in this species probably explain its

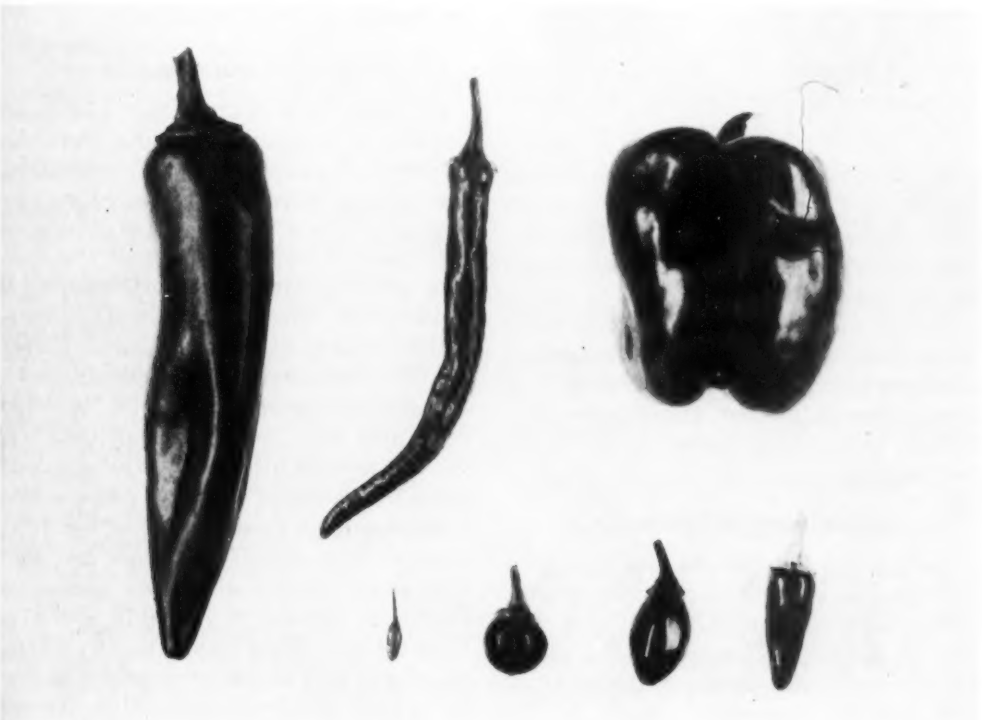

FIG. 6. Variation in size and shape of fruit of *C. annuum*. Top row: California Chili, Long Red Cayenne, California Wonder. Bottom row: Chili Piquin, Paprika variety from Hungary, Mirasol, Floral Gem.

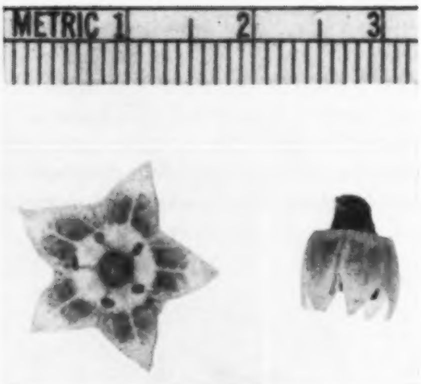

FIG. 7. Flowers of *Capsicum pendulum* showing markings on corolla and the truncate corolla base.

success and wide adoption in the temperate regions.

It was widely used in Mexico in early times, but it was not among the plants consumed by the Indians north of that area, although modern varieties are cultivated successfully today as far north as Canada.

Evolutionary Relationships

Before any conclusions can be drawn in regard to the origin and development of the cultivated peppers from wild species, a better knowledge of the small fruited cultivated forms and the truly wild species is needed. Many of the "wild" peppers have been gathered by many peoples for the same use to which the cultivated forms are put. While those "wild" forms along the southern margin of the United States apparently are mostly *C. frutescens* and "*C. baccatum*", there are many other small fruited varieties described from Central and South America which are poorly known at present. The relationship of *C. annuum* and *C. frutescens*, among the cultivated species, still poses many problems. These occupy much the same geographical areas and there is considerable overlapping of morphological characters. This could well be the result of occasional hybridization at some time in the past or the result of parallel development after divergence from a common ancestor. With the large number of wild species yet to be grown for study as well as the possibility that still other cultivated species may exist, any speculation about relationships at present would be meaningless. Our knowledge of genetical relationships is also as yet too meager to be of much help.

Cytology and Genetics

Chromosome Numbers. The basic haploid chromosome number in the *Capsicum* is twelve, and this number has been found in all the cultivated species discussed above. Natural polyploidy is not known to occur in any of the species, although Greenleaf (**11**) reported a spontaneous tetraploid in an intra-varietal cross, and Györffy (**12**) and Pal et al. (**27**) have induced polyploidy in *C. annuum* by use of colchicine. Haploids have also been reported in peppers (**7, 22, 38**), and their possible value in plant breeding programs has been pointed out.

Interspecific Crosses. In general, it appears that sterility barriers are well developed between all of the species of *Capsicum* considered here (**15, 36, 37**). Thus far it has been impossible to cross *C. pubescens* with any other species. A few F_1 hybrids has been obtained in crosses involving *C. pendulum*, *C. annuum* and *C. frutescens*, but the plants secured were all highly sterile. Thus there appear to be genetic grounds for the recognition of four distinct cultivated species. Any plant breeding program, therefore, in which interspecific hybridization is contemplated would appear to offer difficulties, although by no means have the possibilities of interspecific hybridization been exhausted. To mention one, the creation of polyploids from the highly sterile species hybrids through colchicine treatment should be investigated.

Inheritance Studies. The early work on the genetics of *Capsicum* has been summarized by Boswell (**5**). Since that

time there have been several other studies which have verified the earlier works for the most part as well as adding certain new observations (16, 20, 21, 25, 34, 35, and others). Most of the inheritance studies have been concerned with simple genetic characters. Those of economic significance, whose inheritance is definitely known, are summarized below:

Character	Genes	F_1 Expression	F_2 Segregation
Mature Fruit Color			
Red vs. yellow	R-r	Red	3 Red : 1 Yellow
Brown vs. yellow	Rcl-rCl*	Red	9 Red : 3 Brown : 3 Yellow : 1 Green
Immature Fruit Color			
Green vs. Yellow	G_1G_2-g_1g_2	Green	3 Green : 1 yellow and 15 Green : 1 yellow
Fruit Position			
Pendent vs. erect	P-p	Pendent	3 Pendent : 1 erect
Fruit Shape			
Blunt vs. non-blunt apex	D-d	Intermed.	3 non-blunt : 1 blunt
Bulged vs. non-bulged base	F-f	Bulged	3 bulged : 1 non-bulged
Deciduous Ripe Fruit			
Decid. vs. non-decid.	S-s	Deciduous	3 Decid. : 1 non-decid.
Fruit Pungency			
Pungent vs. mild	....	Pungent	3 Pungent : 1 mild
Inflorescence			
Non-umbel vs. umbel	....	Non-umbel	3 non-umbel : 1 umbel
Tobacco-mosaic Resistance			
Resistant vs. susceptible	L-l	Resistant	3 Resistant : 1 suscept.

*The Cl-cl genes control the breakdown of chlorophyll in the ripening fruit. The dominant Cl gene permits normal decomposition whereas the recessive cl results in retention of chlorophyll. The green mature fruit color is due to the masking of the yellow pigment by the chlorophyll, while the brown color is a combination of normal red pigment and chlorophyll.

Characters for fruit shape, length, intensity of color, degree of pungency, flesh thickness, most plant growth characters and resistance to a number of diseases are controlled by multiple genes.

Conclusions

There can be little doubt that all of the cultivated peppers were originally of American origin. The peppers are known from prehistoric remains in Peru, were widely cultivated in Central and South America in early times, were unknown in Europe before 1493, and, in addition, all of the species with one exception are native to the new world. The prehistoric peppers from Peru, the widespread and varied uses of the peppers, and the great diversity of species and forms, point to a considerable antiquity for their origin. At present we cannot state whether their original place of domestication was in South America or whether there were two or more independent centers of origin. However, it is becoming increasingly clear that there was at least one or more centers of origin in South America, and there was either a diffusion from there to Mexico or an independent origin in the latter center.

Many problems remain to be attacked, and it seems that several courses of action would be rewarding. First, we need to know more concerning the taxonomy and cytogenetics of the genus as a whole, particularly as to the nature and distribution of the wild species. Secondly, a more thorough investigation of the varieties grown by primitive peoples in both Central and South America, particularly Brazil and the Guianas (32),

needs to be undertaken. Thirdly, a critical study of the early literature, including the herbals, in the light of our recent knowledge concerning the different species, would probably be highly enlightening. Once these matters have been clarified, our knowledge of peppers should be more nearly complete and accurate.

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Utilization Abstracts

Battery Separators and Plates. The plates of opposite charge in lead-sulphuric acid storage batteries must be separated by material resistant to vibration breakage and without mechanical holes but sufficiently porous to permit passage of ions and to maintain a low electrical resistance. For this purpose thin sheets of wood have long been found most suitable, and up to 1941 the wood of Port Orford white cedar (*Chamaecyparis Lawsoniana*), a conifer growing up to 200 feet in height in Oregon and California, was used almost exclusively. Decreasing supply of the wood and increasing manufacture of batteries have turned attention to other woods, and those of Douglas fir, noble fir and Alaska yellow cedar have been found most suitable substitutes.

" In spite of the fact that the separators are exposed to the hydrolyzing action of concentrated sulfuric acid, which may be at the boiling temperature of water under heavy charging conditions, the wood is usually the last part of the battery to fail. If untreated wood is used, some of the easily hydrolyzable hemicellulose is converted into simple sugars, and organic acids which are detrimental to the battery are produced. For this reason, and in order to increase the ion permeability and decrease the electrical resistance, wood used for battery separators is extracted with alkali to remove the major portion of the hemicellulose. The lignocellulose residue, which consists principally of alpha-cellulose and lignin, becomes the separator. The lignin is inert to the action of the sulfuric acid and the alpha-cellulose reacts very slowly ". (A. J. Stamm and E. E. Harris, *Chemical Processing of Wood, pp. 557–559. 1953*).

Dragon's Blood. In making zinc etchings, or line cuts, in order to print drawings in ECONOMIC BOTANY and other publications, the original drawings are photographed and the negative transferred to a zinc plate covered with a light-sensitive coating. Exposure to a strong light causes the photo-sensitive coating to harden under the translucent lines of the negative, after which the rest of the coating is washed away with water, exposing the zinc except along the lines where the photo-sensitive coating has been hardened. Then, by five or six dippings in an acid bath, the zinc is etched away between the lines, and in order to protect the lines against the etching action, the plate is dusted with a reddish powder, which adheres to the lines, and briefly heated between dippings. This repeated dusting and heating covers the face and the side of the lines with an acid-resistant coating as the plate is etched to the proper depth, and the quality of work depends upon the skill of the photo-engraver who does the dusting and dipping by hand.

The powder used for this purpose is known as " dragon's blood ". It is a dark reddish-brown resin collected from the surface of the fruits of eight or more species of *Daemonorops*, the climbing jungle palms of Malaya, Borneo and Sumatra, which are the source also of rattan cane. In addition to its use in making zinc line engravings, this resin is employed in the manufacture of spirit varnishes for metals.

New Jersey Tea. In the days of the American Revolution, when tea from India was unpopular because of the tax on it, a favorite substitute was found in the dried leaves of a small white-flowered shrub, since known as New Jersey tea (*Ceanothus americanus*), native from Canada to Texas and Florida. A red dye in the roots accounts for at least one local name, " red root ".

Chinese Chestnut—*A Promising New Orchard Crop*

This chestnut, resistant to the annihilating blight of the American species, gives promise, in selected varieties, of providing an American source of edible nuts comparable to those now imported from Europe and threatened with extermination by the same blight.

JOHN W. McKAY AND H. L. CRANE [1]

Introduction

The Chinese chestnut (*Castanea mollissima* Blume) was introduced into the United States in 1907 (6), and since that time small plantings have been made on a trial basis over a wide area. It is resistant to the introduced Asiatic blight that killed the native American chestnut (*C. dentata* (Marsh.) Borkh.). This resistance has been largely responsible for the interest in planting Chinese chestnut. From pioneer days the American chestnut was intimately connected with the American scene, as it furnished excellent poles, fence posts, fence rails and lumber for all types of building purposes, and the nuts were used as food during the fall and winter. The tree trunk, including the bark, was one of the most important sources of tannic acid for the tanning of heavy leather used for shoe soles, beltings and other purposes. The destruction of the American chestnut by blight was therefore a serious economic loss in the East. As a result, efforts are being made through breeding and selection to develop a timber-type chestnut that will replace the American chestnut. The work of Graves (10), formerly of Brooklyn Botanical Garden, and that of Division of Forest Pathology, Bureau of Plant Industry, Soils, and Agricultural Engineering (3, 4, 7), are examples of the type of work being carried on. Most of these workers have crossed American chestnut with Chinese chestnut or other species resistant to blight in the hope that the hybrids will have the timber characteristics of the American parent and the blight resistance of the other parent. Some of the results of this work have been promising, but as yet no types that have the desired combination of characteristics have been developed.

Meanwhile return of the chestnut to the American scene is taking place rapidly. This has been accelerated by the selection and development of new horticultural varieties or clones of Chinese chestnut that are superior for nut production to most trees grown from seed of this species that had been previously introduced.

There is a great deal of interest in planting Chinese chestnut around homes for production of nuts for home use. Chestnut blight has recently been reported from several localities in Europe (16). Since the European, or Italian, chestnut (*C. sativa* Mill.) is highly susceptible to attack by the blight organism, it is probable that this species will be destroyed in Europe to the same extent as were both European and American chestnuts in the eastern United States. Foreign imports of European chestnuts into this country will then be largely cut off, and it will be necessary

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FIG. 1. A 12-year-old Chinese chestnut tree that produced one bushel of nuts in 1949. Note the spreading and rounded form of the tree, which provides a large number of terminals for heavy production of nuts.

for the United States to produce most of the chestnuts consumed here. This means that the Chinese chestnut will probably find a place in American agriculture both to supply nuts for domestic consumption and to help maintain world production of nuts as a source of food.

This article discusses the Chinese chestnut and points out some of the requirements for its culture, based on experience with new varieties selected during the past decade.

FIG. 2. Terminal portion of Chinese chestnut shoot in full blossom. The staminate, or male, catkins on the basal part of the shoot at A are the first to shed pollen. At this stage they have almost completed the shedding. The pistillate flowers at B are located on the basal part of mixed catkins; at this stage they are fully receptive. The staminate parts of the mixed catkins are shedding pollen.

Description

The Chinese chestnut tree is usually spreading in form and has a rounded top when not crowded by other trees (Fig. 1). A tree may have a spread of 40 feet or more, but usually it grows to the size of a large apple tree or perhaps somewhat larger. The leaves resemble those of the American chestnut closely except that they are shorter and broader and are lighter in color, at least when young. The tree blossoms in early June in the vicinity of Washington, D. C. Its catkins are of two kinds, borne on current season shoots. The first catkins to flower are staminate, or male, and are located on the lower portion of the flowering shoot (Fig. 2, A). Later mixed catkins produced just above the staminate catkins come into flower; these produce both staminate flowers and pistillate, or female, ones (Fig. 2, B). So far as is known, all chestnuts are self-sterile (13); that is, every tree is almost entirely self-unfruitful, and all must be cross-pollinated with pollen from another tree in order to produce a good crop of nuts. It is important, therefore, that one or more trees of at least two varieties or seedlings be planted in order to insure cross-pollination. Many workers believe that chestnuts, like walnuts, pecans, oaks and a good many other forest trees, are wind-pollinated. Others believe, however, that chestnuts are insect-pollinated, since the flowers are very fragrant and the staminate catkins produce large quantities of nectar (18); also, several species of insects visit the catkins in large numbers while they are in bloom. This is further indication that insects probably play a part in the transfer of pollen.

The fruit of the Chinese chestnut is borne in a spiny involucre commonly known as the "bur". Three nuts are normally produced in each bur (Fig. 3). Botanically each nut is a complete fruit. The shell develops from the ovary wall. The kernel is enclosed in a membranous covering called the "pellicle". One of the oustanding features of this nut is the ease with which the pellicle can be removed from the kernel as contrasted with the fibrous and folded nature of the pellicles of European and Japanese (*C. crenata* Sieb. & Zucc.) chestnuts. This makes nuts of the Chinese chestnut much easier to prepare for eating than those of the other species.

The Chinese chestnut produces nuts

FIG. 3. Bearing shoots of Nanking variety of Chinese chestnut, showing the characteristic three nuts per bur and the clusters of two or more burs on each bearing shoot, typical of the new heavy-bearing varieties.

that are very sweet and palatable when properly cured. Most observers consider the nut of this species when properly cured as desirable for eating as that of the American chestnut (Fig. 4).

Uses

The American chestnut was widely used in the East from pioneer days as an article of food, and it is possible that the Chinese chestnut will find its place in the American diet if it can be produced profitably. In the Mediterranean region the European chestnut is an essential item of food, used very much as wheat in this country. The nuts are dried and made into flour for soups, porridges and even bread.

The greatest potential use of Chinese chestnuts in this country, at least in the initial stages of production, is probably the same as that of the American chestnut and peanut, namely, as an accessory article of food in late fall when they were roasted by street corner vendors in all eastern cities and during the Thanks-

giving and Christmas seasons for stuffing fowls. The Chinese chestnut offers promise of being widely used as yard trees; since modern home refrigeration has become available to large numbers of people, the nuts produced by these trees may be stored conveniently as an item of food. There is little question that the varieties recently selected and developed will rank high among other agricultural crops as carbohydrate producers on a per acre basis. This is due to the fact that they yield such heavy crops of nuts. It is not likely that the people of the United States will dry chestnuts and use them the same way Europeans do. Nevertheless, when they become acquainted with the high quality and palatability of the nuts of the Chinese chestnut, this product should find ready market.

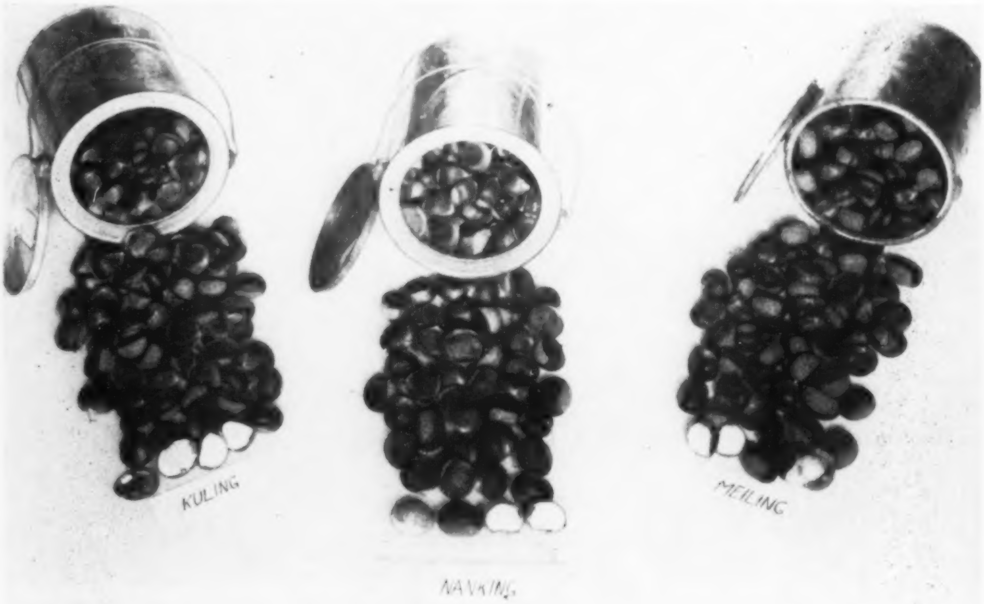

FIG. 4. Nuts of three varieties of Chinese chestnuts recently introduced, namely, Kuling, Nanking and Meiling. Note the crimped-topped cans in which the nuts are stored.

Soil and Climatic Requirements

Experiments carried on so far have shown that Chinese chestnuts grow best on sandy soil or sandy or gravelly loam that is well drained and underlain by a friable clay subsoil. As a rule the soil should be moderately to slightly acid, but in a few instances well fertilized and well cared-for trees are known to grow well on a slightly alkaline soil. It is definitely known that the trees will not grow on low ground that is poorly drained. There are some indications that the trees will withstand a moderate amount of drought when well established. Near Oklahoma City, Oklahoma, trees in one planting are known to produce regular crops of nuts, even though frequent droughts are commonplace (12). Chinese chestnut trees thrive on ample moisture, however, and adequate rainfall is essential for the production of heavy crops of nuts of desirable size.

As much attention should be given to selecting a site for Chinese chestnut trees as is given to the matter of type of soil in which they are planted. The trees should be located on high sloping

ground in order to provide adequate air drainage to prevent damage from late spring frosts. Although the Chinese chestnut tree blossoms late in the spring, the catkins, so far as we know, are formed in the buds before or soon after growth begins in the spring. They are therefore subject to killing in the same manner as are buds and flowers of peach and other fruit trees. The Chinese chestnut tends to start growth early in the spring, and danger of injury from late spring frosts is present as soon as the buds begin to swell. Trees located on low ground or in frost pockets are almost sure to be injured by freezes in late spring. In some cases whole limbs or even the entire tree may be killed if growth activity has been enough to make the tree susceptible to frost damage.

It is not known how extensively the Chinese chestnut can be grown in the United States. However, there are indications that it is well suited to conditions in the southeastern part of the country. The tree seems also to be definitely hardy in the northern part of the country as long as it is completely dormant. The reason why the species may possibly not be fully successful in more northerly regions is that the tree tends to respond quickly to warm periods of weather early in spring and therefore becomes susceptible to injury from frosts that sometimes follow these warm periods in certain localities. This quick response to warm periods in early spring is due to low chilling requirement which means that only a small amount of cold weather is needed to satisfy the dormancy requirements of the tree. The Chinese chestnut has not yet been grown extensively enough in the northern part of the country to demonstrate its suitability for these areas. Present indications are that it probably will be suited to the northern parts of the eastern United States when appropriate sites are selected. It is believed that it can be successfully grown in all areas and under conditions that are suitable for peaches. Hardy (11) reported that the long growing season characteristic of the Southeast may be largely responsible for the success of Chinese chestnut there. It remains to be determined whether the new varieties will produce heavy crops of nuts in the northern part of the country, where the growing season is much shorter.

At present most Chinese chestnut trees growing in this country are seedlings, and every tree is different in its characteristics from every other tree. Until grafted horticultural varieties are planted extensively in various parts of the country, no definite information can be obtained as to the response of varieties to different conditions of soil and climate. The greatest single need in the Chinese chestnut industry at present is plantings of trees of a number of horticultural varieties over an extensive area in order to provide information regarding their suitability for nut production in different parts of the country.

Orchard Management and Cultural Practices

In orchard plantings Chinese chestnut trees should be spaced at least 40 feet apart on the square; 50 or 60 feet is better. This gives the trees plenty of room to develop into the spreading rounded form that is necessary for heavy nut production. It is also necessary to plant two or more varieties in an orchard to insure cross-pollination. All chestnuts, as far as is known, are almost entirely self-sterile (13), and a single tree isolated from other trees will not produce more than a handful of nuts. Row crops of various kinds, such as corn, cotton and beans, can be grown in the orchard for the first few years. On sloping land it is desirable to plant the trees on the contour in order to avoid excessive erosion. In the northern part of the country it is best to plant in early spring.

but fall planting is successful in the Southeast. On acid soils that have a low level of calcium and magnesium, it is desirable to apply dolomitic limestone at the rate of 500 to 2,000 pounds per acre, depending on the acidity and lime requirement of the soil, and to disc it in before the trees are planted.

Cultivation practices will vary with climatic conditions in different parts of the country. Regardless of climate young chestnut trees that are not cared for after transplanting cannot compete with grass and other weeds for moisture and plant food elements in the soil. Newly transplanted trees, even in cultivated orchards, should be hoed so as to keep an area six feet in diameter around each tree free of grass and weeds from the time of bud swelling in the spring until the middle of July. This practice should be followed the first three or four years after transplanting in order to allow trees to become well established. For established orchards in the Southeast, Hardy (11) recommended a system in which blue lupine, hairy vetch or Austrian winter peas are grown as a winter cover crop and disced under during the very early spring. Before this cover crop is planted in October, 0–14–10 or 0–14–7 fertilizer at the rate of 400 to 600 pounds per acre is broadcast over the land and disced under. The green manure cover crop is disced under about April 15 of the following spring, and shallow cultivations are given the orchard during the summer to keep down excessive weed development. The ground should be clean by the first of September in order to facilitate the harvesting of nuts. If such a system of culture is not feasible, as on steep slopes or around buildings, Hardy (11) recommended mowing and mulching the trees with the cover crop; but the trees must be given annual applications of a complete fertilizer mixture, such as 4–8–6, 6–8–8 or 5–10–5. Under the latter system of management, the fertilizer should be applied broadcast evenly underneath the tree before growth starts in the spring at a rate of two to three pounds for each year of tree age.

No definite information is available on the types of cover crops or orchard management practices that can be used in the more northerly parts of the country. This is due to the fact that the Chinese chestnut has not yet been grown extensively enough in this part of the country to yield such information. In general, it can be said that on sloping land contour planting is recommended, and perhaps the best procedure to follow in established orchards is to use a sod covering that is mowed during the summer, with adequate fertilizer applied around the tree in the early spring (Fig. 5).

Chinese chestnut trees should be pruned very little during the first few years in the orchard, since early pruning tends to make the trees vegetative and postpones the date when they come into bearing. A few seedling Chinese chestnut trees will bear at four to six years of age if they are not pruned. Grafted trees usually bear at least one year sooner than seedlings, and frequently they bear while they are very small (Fig. 6). Some pruning can be given the trees after they have been in the orchard for two or three years to remove the lower limbs and gradually raise the head of the tree, so that cultivation equipment can pass underneath them.

Varieties

At present only a few horticultural varieties of the Chinese chestnut have been propagated, and only a limited number of nurserymen list grafted trees for sale. Reed (17) described all the horticultural varieties that had been generally propagated at the time he wrote. Many of the varieties that he mentioned are already obsolete and no longer propagated. Most of the Chinese chestnut trees being planted in this coun-

try at present are seedlings, and it is probable that out of them may come some new varieties after they have fruited and the superior ones have been selected. The planting of Chinese chestnuts today can be compared in many ways with the pecan industry at the end of the past century, when seedling pecan trees were largely grown. As interest increased in the production of pecans on an orchard basis, new varieties suited to particular areas were selected, and it was not long until the so-called paper-shelled pecan was developed. Similar progress is likely to be made with the Chinese chestnut. As soon as the need of an orchard industry is realized, it is likely that superior seedlings among the existing plantings of Chinese chestnuts will be discovered and propagated, giving rise to new horticultural varieties suited to different climatic conditions.

The United States Department of Agriculture recently released three new varieties known to be suited to the southeastern part of the country. Seeds from which the original trees of these varieties were grown were imported from central China by the Division of Forest Pathology, Bureau of Plant Industry, Soils, and Agricultural Engineering, U. S. Department of Agriculture, in **1936**, and this Division has also investigated the various diseases that attack the Chinese chestnut. How widely these varieties will be suited for growing in other areas is yet to be determined. The varieties have been given the Chinese names "Nanking", "Meiling" and "Kuling" (2). Nurserymen have already distributed them widely in small numbers, so that within a few years definite information will be available concerning their suitability for different areas. The new variety Abundance seems to offer promise of being superior in many ways to the older varieties.

FIG. 5. Ten-year-old grafted Chinese chestnut trees grown on poor soil with a sod covering mowed once or twice each growing season. These trees, photographed in June at the time of full blossom, show the compact and low heading that result from little or no pruning. Orchard trees six to eight years old grown in this manner bear heavy crops of nuts if adequate fertilizer is added to the soil around each tree in the spring.

Propagation

The Chinese chestnut is propagated at present largely from seed. It is in this manner also that rootstocks are grown for use in grafting horticultural varieties. Chestnut seed should be harvested

FIG. 6. A grafted chestnut tree that has been growing in the orchard four years on very poor soil without cultivation. This tree has made very little growth but is bearing a fair crop of nuts, even under such adverse conditions. It shows how grafted trees bear while very small.

promptly in the fall and placed under proper conditions of storage until the seed is planted in the spring. One of the best methods of keeping the seed over winter is to place it in one- or five-gallon cans with tight-fitting crimped-top lids (Fig. 4), in which one to three holes, 1/16 to 1/8 inch in diameter, are punched

FIG. 7. The nursery of Chinese chestnut seedlings photographed in July of the year in which the nuts were planted in March. These seedlings, planted according to the bed method described on page 238, averaged almost four feet in height at the end of the first season's growth.

for aeration (5). These cans should be stored at 32° F. for best results, although the nuts may be successfully stored at somewhat higher temperatures. The nuts are often stored in boxes containing slightly moist sawdust or sphagnum moss and kept in cool cellars or basements. If this method is properly followed, very good results may be obtained, but use of crimp-top cans is preferred.

As soon as the soil becomes workable in the spring, the nuts are taken from storage and planted in the nursery where the seedlings are to grow for the first year. The seed may be planted in rows four feet apart and three to six inches apart in the row or in beds two feet wide.

In beds the nuts are planted four inches apart in drills spaced four inches apart across the bed. This method involves intensive cultivation of a smaller area of ground for growing a given number of seedlings than does the row method and is perhaps desirable from the point of view of low cost of upkeep (Fig. 7).

Most workers report difficulty in budding chestnuts. This is due partly to the fact that the wood is slightly fluted, and with any method of budding it is impossible to make an accurate fitting of the bud to the stock. Some success has been obtained by using one-year-old seedlings as stock and placing shield buds (T-buds) very low on the seedling early in the spring. More experimental work must be done before chestnuts can be budded successfully in the nursery.

There have been some reports of difficulty in grafting horticultural varieties of chestnuts when understocks of unknown parentage were used. The experience of different nurserymen and growers with grafting techniques and procedures has been so varied that much more experimental work will have to be done on this problem before definite information will be available. There is considerable evidence that graft union failure may be held to a minimum if pure Chinese chestnut seedlings are used as understock for Chinese chestnut varieties. Since chestnut species hybridize freely (14) and many of the present plantings of chestnuts used in this country as a source of seed contain more than one species, it is likely that the resulting hybrid seedlings may have been responsible for the failure of graft unions in a great deal of the propagation work up to this time.

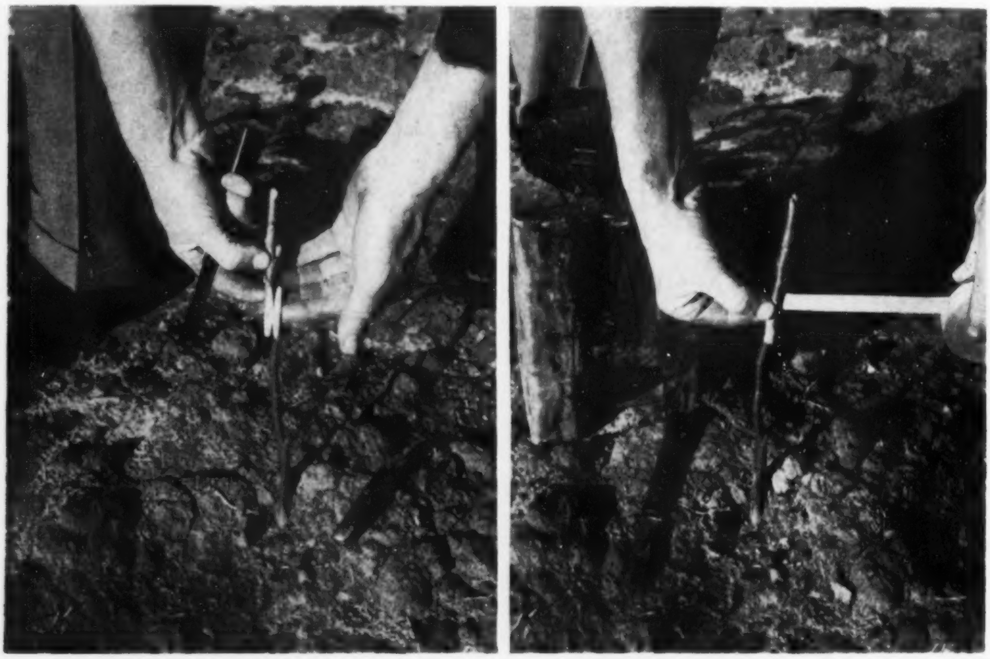

FIG. 8. The essential steps in the splice method of grafting. *Left*—The scion and stock, which should be of approximately the same diameter, are cut with the same slanting cut, so that the two exposed surfaces fit snugly together. *Right*—The scion and stock have been joined and the union is being wrapped with paper masking tape, after which the whole is completely covered with grafting wax to protect the cut surfaces against drying out.

The best method of grafting chestnuts

appears to be the ordinary splice graft method. Several nurserymen have used this method for a number of years, and it seems to combine ease of execution with the speed that is necessary in order to make the method profitable from the nurseryman's point of view (Fig. 8). At present there is very little information available as to the best stocks to use in grafting the improved horticultural varieties of Chinese chestnut. There is some indication that certain horticultural varieties will give better performance on understock derived from seed of known parent trees (15). It is possible that the propagation of chestnuts will follow somewhat the same lines as did development of other tree fruit crops, and a knowledge of understocks should develop hand in hand with the need for propagation of new varieties. This is especially true in view of the fact that the demand for grafted trees will stimulate nurserymen and research agencies to do further experimental work to develop the proper understocks for improved horticultural varieties.

Harvesting and Storing the Nuts

Chestnuts are starchy and very different from other nuts, most of which contain large amounts of oil. Fresh chestnuts contain 40 to 45 percent carbohydrates, mostly in the form of starch, about five percent oil, and about 50 percent moisture. They are highly perishable, even more so than apples, and must be harvested and handled accordingly. Unless properly handled, they dry out rather quickly and become hard and bony, in which condition they cannot be roasted or boiled satisfactorily without prior soaking. There are a number of fungi and bacteria that attack the nuts, causing them to decay or otherwise spoil (9).

Hardy (11) stated: "The perishable nature of the nuts of the Chinese chestnut has probably been the greatest drawback to an earlier acceptance of this crop as an adjunct to the horticulture of the southeast". This statement is based upon the tendency of Chinese chestnuts produced in the Southeast to mold badly during handling and storage. This tendency to spoil varies greatly among nuts from different seedling trees. In other words, the nuts from certain trees have better keeping quality and more resistance to spoilage than nuts from other trees. In an orchard of seedling trees, where the nuts from all trees are harvested and handled as a mixed product, it is therefore certain that an unpredictable amount of spoilage will occur. Hardy (11) stated: "Storage losses through periods up to six months have been held to less than 10% for a mixture of nuts from all of the trees at Philema. Storage tests of nuts from individual trees have shown a range in keeping quality from no loss after six months' storage to nearly 100% loss". This indicates that the storage problem eventually may be solved by selecting as new varieties trees that produce nuts relatively free from mold under suitable storage conditions. This also emphasizes the value of planting grafted trees instead of seedling trees because in the former case the storage quality of the nuts is known, whereas with seedling trees no prediction can be made as to the keeping quality of the nuts.

It is important that the nuts be harvested at least every other day so that they will not be on the ground more than two days at a time. This is especially important where there is high light intensity, as the hot sun will cause rapid deterioration of the kernel, resulting in poor keeping quality. At the end of each day the nuts are placed in cold storage in ventilated tin cans, as described under Propagation, where they are to remain until used. A temperature of 32° F. with 85 percent relative humidity is recommended, although the nuts may be stored in an ordinary home refrigerator if placed in proper containers.

Yields

Little information is available on the capacity of the Chinese chestnut to yield crops of nuts under different climatic conditions and in different parts of the country. There is some indication that factors determining yielding capacity are inherited, since there is great variation among seedling trees as to bearing habits, and certain high-yielding seedlings continue to bear heavy crops after being grafted or topworked to other trees. One of the main advantages of planting grafted trees of improved varieties is that they yield uniform crops of nuts under optimum conditions of growth. If seedling trees are planted, it is almost certain that some will yield unsatisfactory crops of nuts, even under optimum conditions; and the proportion of poor-yielding trees is often high. For example, in an experimental orchard of 400 to 500 seedling trees planted in the spring of 1936 at Plant Industry Station, Beltsville, Maryland, not more than a dozen yielded satisfactory crops of nuts after 10 to 12 years observation, and most of the trees have been removed. In another orchard planted in the spring of 1938 at Philema, Georgia, a much higher proportion of the seedling trees yielded satisfactory crops of nuts, and a few have been outstanding as heavy bearers of large good-quality nuts. The new varieties Nanking, Meiling and Kuling were propagated from three of the best trees in this orchard. The difference in performance between these two orchards of seedling trees indicates the variation that is likely to be encountered in using seed from different sources. The orchard at Philema has been exceptional in the high proportion of seedling trees that yield large crops of nuts of acceptable size and quality. In commenting on the yield records of the trees in this orchard, Hardy (11) said: "Yield records at Philema, Georgia, show actual yields of more than 1000 pounds per acre, and potential average annual yields of 1500 or more pounds per acre are not out of reason". When it is considered that grafted trees of the three new varieties, Nanking, Meiling, and Kuling, originating in this orchard will bear earlier than the original seedling trees, the indicated production on an orchard basis, with the trees 40 feet apart, should be reached in five to eight years after grafted trees are planted. This estimate is based on performance of the trees in the Philema orchard. It should be emphasized that these new varieties have not been tested long enough in other sections of the country to indicate whether such performance can be expected in other localities.

Insects and Diseases

There are two classes of insects that attack the Chinese chestnut and cause a great deal of damage in some parts of the country, namely, the Japanese beetle and two species of chestnut weevil. These insects can be controlled by spraying the trees at the proper time with DDT. Mimeographed directions for this work have been issued by the Bureau of Entomology and Plant Quarantine, Agricultural Research Center, Beltsville, Maryland. Directions for control of chestnut weevils are as follows: "Spray the trees with DDT three times at intervals of about 12 days. In the vicinity of Washington, D. C., the best date to begin spraying is usually about August 15, but it varies from season to season and place to place. To prepare the DDT spraying material, add 4 pounds of a 50-percent or 8 pounds of a 25-percent DDT wettable powder to 100 gallons of water. For small quantities of spraying material, add two-thirds ounce (approximately 16 level tablespoonsful) of a 50-percent powder or one and one-third ounce (about 32 level tablespoonsful) of a 25-percent powder to 5 gallons of water. Mix the DDT powder thoroughly with water". (As DDT is a poison, it should be handled carefully in

accordance with manufacturer's directions.) For control of the Japanese beetle the above material should be applied as a spray to the trees when the insects are numerous. Usually one application is sufficient, but later ones may be required if the beetles become numerous again. The Japanese beetle destroys the foliage of the trees, especially the younger and more tender leaves. Larvae of the chestnut weevils feed upon the kernels of the nuts and give rise to a condition known as "wormy" nuts. Where chestnuts have not grown for some time, it is likely that chestnut weevils will not give trouble for some years because of the period required to build up a population of grubs which over-winter in the soil. The larvae of the filbert moth has been known to cause damage by burrowing in the base of the bur and causing a flow of sap which ferments and spoils the chestnuts.

The Chinese chestnut is relatively free of fungus diseases that cause serious damage. The chestnut blight fungus may attack Chinese chestnut trees, but this species is highly resistant to the disease and usually very little damage results. In some localities, trees are attacked by an organism that causes root rot, but this usually is of little importance, provided they are planted on suitable soil (8). Recently it was reported (1) that Chinese chestnut trees growing in Missouri were attacked by the oak wilt fungus.

Outlook

The growing of Chinese chestnuts for nut production is definitely an infant industry. How far it will develop depends upon many factors. The eventual success of the industry as a commercial venture will depend upon imports from foreign countries, consumer demand, production costs and price received for the product. The American chestnut has been absent from the American scene so long that only a small percentage of our population knows and appreciates chestnuts as an article of food. At present our supply is dependent on imported nuts, largely of the European species. Total imports vary widely from year to year, but recently they have ranged from 7,000,000 to 20,000,000 pounds.

On the basis of preliminary results with recently selected varieties of the Chinese chestnut, it seems definitely possible that chestnuts may be produced at the rate of 1500 or more pounds per acre with proper orchard management and in suitable locations. This means that with any reasonable price the production of nuts on an orchard basis should prove to be a profitable undertaking. Moreover, wide use of the Chinese chestnut as a tree for yard planting seems assured because of the heavy yielding capacity of the new varieties and their general utility as a shade and ornamental tree. Preliminary results indicate that the tree is suited to a wide area of the eastern United States, but whether heavy yields will result when the selected varieties are planted in the northern part of this area remains to be determined. At present nurserymen throughout the country are selling mostly seedling trees, and relatively few grafted trees of horticultural varieties are being sold. Because of this fact many growers will be disappointed when their trees come into bearing because many seedling trees bear small nuts and in many instances very light crops.

The importance of planting grafted trees of selected horticultural varieties cannot be over-emphasized. Grafted trees will cost more in the first place, but the grower who plants such trees will be rewarded by superior performance in later years. If the present status of the chestnut industry can be compared to a similar epoch in the history of apple growing, it can be said that we are now in the "Johnny Appleseed" era. Probably before stability is reached in the

growing of chestnuts on an orchard basis, many new horticultural varieties will have to be developed and tested in order to originate varieties suited in particular areas.

Because seedling trees are being widely planted over the eastern part of the country, growers can make a definite contribution to the development of the industry by selecting outstanding seedlings for propagation and testing them as possible new varieties. This will mean careful attention to selecting trees that have good characteristics in productiveness, vigor, early bearing, and large and atractive nuts with good eating and keeping qualities. Trees that have these and possibly other desirable characteristics should be propagated and tested as potential varieties for the area in which they occur. If this is done in many localities over the country, new varieties with characteristics that make them suiable for growing in different parts of the country will be rapidly developed. Eventually the industry will be developed on the same basis as the growing of peaches and apples and other tree fruit crops. The product from orchards will then be uniform with respect to appearance, keeping quality and other characteristics that are important from the consumer's point of view. With the chestnut blight ravaging large areas of the Mediterranean region of Europe and thus threatening the supply of future imports, and with interest increasing in the possibilities of the new crop for domestic use, the production of nuts by blight-resistant Chinese chestnut trees appears to be promising in this country.

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Contributions of Applied Science to the Lettuce Industry of the Southwest

Integrated achievements of plant breeders, soil scientists, agricultural engineers and refrigeration specialists, along with increased market demands, have raised the American lettuce industry from a $6 million business in 1918 to one of $108 million in 1949.

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Introduction

Economic History. Despite its non-durability, we know that lettuce has been widely used as a food plant by man since early times. According to Meunissier (9), the records of the herbalists indicate that lettuce was eaten by the Persians as early as 550 B.C. and was in general use in the Old World at the beginning of the Christian era or earlier. Apparently, lettuce was plentifully grown by all peoples throughout the period covered by modern history.

Lettuce has been widely grown in American home gardens since the days of the early settlers. It became a commercial crop of some importance with the development of local market gardens near large cities concurrently with the growth of the country. However, outdoor production was limited by the short growing season. At the turn of the century the growing season was extended by forcing culture during fall, winter and spring in greenhouses near large population centers (11). During this period lettuce remained a seasonal food item for most American families, although it could be procured as a luxury item in large population centers throughout the year. With expansion of the lettuce industry in the southwestern United States and particularly in the mid-winter producing areas, lettuce became available to the average American family at moderate prices at all seasons of the year.

The commercial lettuce crop in the United States increased in value from $6,176,000 in 1918 to $108,394,000 in 1949. This phenomenal rise of lettuce to the status of an important vegetable crop resulted from increases in population and increases in per capita consumption. The annual per capita consumption of head lettuce soared from two and one-half heads in 1918 to slightly over a dozen heads in 1947 (4).

The growth of lettuce culture from a minor seasonal and forcing culture industry to a major vegetable crop industry resulted from the development of irrigated lands in the arid Southwest and the development of country-wide shipping of fresh produce in refrigerated cars. It would have been impossible to achieve the gains that have been made without exploiting the techniques of plant breeders, soil scientists, agricultural engineers and refrigeration engi-

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neers. Integration of the contributions from these several disciplines by growers and shippers has produced a remarkable advance in the production and marketing methods used for this commodity. This report attempts to record the contributions of applied science to the lettuce industry, particularly in the Southwest [3].

TABLE I

ACREAGE, PRODUCTION, YIELD PER ACRE, AND VALUE OF THE LETTUCE CROP IN THE SOUTHWEST, 1922-1949, INCLUSIVE. (COMPILED FROM U. S. DEPARTMENT OF AGRICULTURE YEARBOOKS AND AGRICULTURAL STATISTICS.)

Year	Acreage harvested	Production (crates)	Yield per acre (crates)	Value per crate ($)	Value per acre ($)	Farm value ($)
1922	19,620	4,203,000	214	1.38	295	5,800,000
1923	27,600	7,398,000	268	1.19	319	8,804,000
1924	25,800	5,005,000	194	1.45	281	7,257,000
1925	29,400	6,040,000	205	1.39	285	8,396,000
1926	73,600	12,371,000	168	1.74	292	21,526,000
1927	92,340	14,298,000	155	1.11	172	15,871,000
1928	99,620	14,450,000	145	1.71	248	24,710,000
1929	115,030	15,453,000	134	2.04	273	31,524,000
1930	149,120	15,505,000	104	1.89	197	29,304,000
1931	151,750	15,557,000	103	1.55	160	24,113,000
1932	138,570	13,954,000	101	1.43	144	19,954,000
1933	118,500	13,689,000	116	1.42	165	19,438,000
1934	131,050	15,283,000	117	1.52	178	23,230,000
1935	131,510	15,931,000	121	1.54	186	24,534,000
1936	146,940	18,580,000	126	1.53	193	28,427,000
1937	132,900	17,916,000	135	1.70	230	30,457,000
1938	129,750	16,433,000	127	1.55	197	25,471,000
1939	147,250	20,315,000	138	1.47	203	29,863,000
1940	118,400	18,298,000	155	1.51	234	27,630,000
1941	131,900	19,489,000	148	1.71	253	33,326,000
1942	132,690	20,065,000	151	2.56	387	51,366,000
1943	111,100	20,632,000	186	3.56	662	73,450,000
1944	143,100	24,817,000	173	2.64	457	65,517,000
1945	146,180	24,996,000	171	2.98	510	74,488,000
1946	175,700	28,702,000	163	2.68	437	76,921,000
1947	159,800	29,457,000	184	3.28	604	96,619,000
1948	169,900	29,110,000	171	3.35	573	97,519,000
1949	166,100	28,600,000	172	3.79	652	108,394,000

As shown in Table I, during the early years of the lettuce industry (1922 to 1925) the yields per acre were exceptionally high in relation to the acreage harvested and total production in crates. There may have been a variety of reasons for the exceptional yields during this period, but undoubtedly the use of new land of high fertility, freedom from diseases, and loose packing of untrimmed heads in the crate were important contributing factors. The yields per acre gradually decreased from 1926 through the depression years, reaching a minimum in 1932. The first part of this period coincides with the appearance of the destructive disease brown blight which caused exceedingly heavy losses up to 1930, when resistant varieties came into general use. During the depression

[3] The Southwest, as used here, consists of the States of Arizona and California. Other southwestern States produce only a negligible quantity of lettuce and were disregarded in compiling Table I.

era the acreage harvested was nearly normal or slightly in excess of normal, but production and yields per acre were low because the fields were usually sparingly harvested as a result of unfavorable marketing conditions.

For the most part after the depression, yields per acre of lettuce showed a steady increase up to 1943, when they leveled off at about 170 crates per acre. Use of resistant and high-yielding varieties, improved methods of farming, and more stable marketing conditions were probably influential in bringing about this change.

The acreage devoted to lettuce in the Southwest made spectacular gains from 1922 until 1930. During this period it increased from 19,620 to 149,120 acres. In the following 13 years from 1931 to 1944 there was some increase in acreage, but it tended to fluctuate around a mean of 132,485 acres, reaching a high point of over 151,750 acres in 1931 and sinking to a low of 111,100 acres in 1943. During the later part of World War II and the post-war years, the lettuce acreage again made a decided increase. For the period 1944 to 1949, the lettuce acreage harvested in the Southwest averaged nearly 160,000 acres each year.

Food Value. In their grouping of fresh vegetables based on food production efficiency, MacGillivray et al. (7) placed lettuce in Group 3, along with cauliflower, celery, asparagus, snap bean and lima bean. The chief food value of lettuce has been found to be the vitamin and mineral content of the leaves. Lettuce is a fair source of vitamins A, B and B_2, and is relatively high in calcium and iron. Since it is eaten uncooked it loses no food value in preparation for the table. Its deserved popularity can probably be traced to taste appeal and low energy value. For these reasons lettuce is an attractive and easily prepared ingredient of most low-calorie diets.

Contribution of Plant Breeders

Development of Uniform Strains. The irrigated lands of the arid southwestern United States are ideally suited for mass production of vegetable crops. Little rain falls in the interior valleys during the winter growing season or in the coastal valleys during the summer growing season. In addition, the farmer has close control of soil moisture and, to a less extent, of soil fertility. Precise control of soil moisture is particularly important with lettuce, since soil moisture is one of the key factors in the production of a marketable crop. Before lettuce could be adapted to mass production methods it was necessary for plant breeders to develop strains that would germinate uniformly and mature a large majority of the heads within a period of two to three weeks. Commencing with the release of the first Imperial varieties of head lettuce by the U. S. Department of Agriculture in 1926 (5), grower-shippers were provided with varieties that would meet these requirements and, in addition, produce heads that were of approximately equal size and shape under a given set of conditions.

Development of Narrowly Adapted and Widely Adapted Varieties. The head lettuce plant is extremely sensitive to slight changes in environment. A variety selected for uniformity and good performance under one set of environmental conditions will usually perform less well under other conditions. Indeed, it may fail to produce any marketable heads under some conditions. This was recognized early in the development of the western lettuce-breeding program of the U. S. Department of Agriculture (1). It led to the production of varieties adapted to culture in different seasons and at different locations.

Slow bolting varieties were developed for culture during autumn. A fall variety of head lettuce must be able to initiate growth in hot weather when the days

are long and produce large firm heads with short stems as the days become cooler and shorter. Cold-tolerant varieties were developed for culture during mid-winter. A winter variety must be able to grow vigorously and produce a large plant when the days are short and the temperatures are low. It must also have abundant wrapper leaves to protect the head from frosts. Varieties adapted to low temperatures during early growth and high temperatures during late growth were developed for spring culture. A spring variety must be able to grow vigorously and produce a large plant during cold weather and yet produce a mature head free from internal tipburn in warm weather. Heat-tolerant varieties were developed for summer culture. A summer variety must be able to form a firm head free from tipburn during hot weather.

For successful lettuce culture most varieties must be grown during the specific seasons to which they are adapted. Temperature, humidity, soil moisture, soil fertility and other environmental factors can fluctuate only within relatively narrow ranges to produce a satisfactory crop. This is especially true at critical stages in the growth period of the plants—at emergence, at initiation of head formation and at maturity. If a variety is planted out of season or if environmental conditions fluctuate too widely, it may produce a loosely folded mass of leaves, or it may bolt before the head matures. If a mature head is formed it may be too small, or it may develop tipburn or other abnormalities.

These considerations suggest that it may be impossible to develop a variety of head lettuce so widely adapted that it will produce summer lettuce in one locality and winter lettuce in another. The variety Great Lakes (Fig. 1) approaches this wide range of adaptation. It forms firm heads under most environmental conditions, and it is slow to bolt and resistant to tipburn. It grows well during cool as well as warm weather. Hence it can be grown in late spring, summer and fall seasons. However, it forms heads that are too small for most markets when it is grown in mid-winter and early spring.

It is not particularly desirable to have a single variety that is universally suitable for culture. It seems likely that a series of varieties suitable for culture at different locations during different seasons will be quite satisfactory. Plant breeders have made considerable progress with this approach. They have produced a great many varieties that are specifically adapted to culture in certain districts at designated growing seasons.

Development of Disease-Resistant Varieties. The development of disease-resistant varieties by plant breeders has contributed immensely to the expansion of the lettuce industry. In fact, without the services of plant breeders, there would have been grave doubts about the survival of the industry in the Southwest. Plagued by economic uncertainty and an apparently hopeless disease situation, it was on the verge of disintegration in 1930, when the Imperial varieties, resistant to brown blight, came into wide use. Varieties that are resistant to brown blight have continued to be the backbone of the lettuce industry in the Southwest. In addition, some progress has been made in developing varieties resistant to the various biological races of lettuce downy mildew (*Bremia lactucae* Reg.).

Development of the modern lettuce industry has been directly dependent upon the varieties produced by American plant breeders. Expansion of the industry has been promoted by a long-term systematic breeding program responsive to the problems of the industry as they developed. The success of plant breeders in the exploitation of the lettuce plant is well illustrated by the large

number of varieties available for culture during all seasons of the year, by the healthy growth and expansion of the industry, and by the presence of high quality lettuce in markets throughout the country at all seasons.

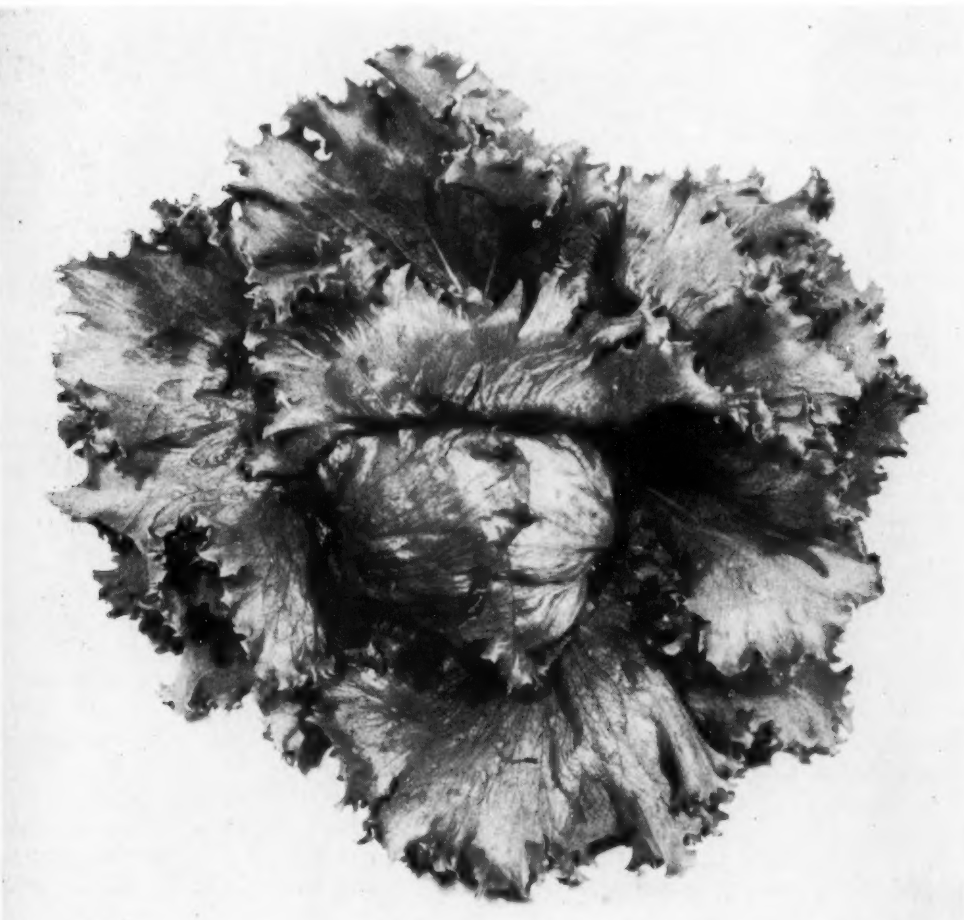


FIG. 1. A marketable head of the Great Lakes variety of lettuce.

Contributions of Soil Scientists and Irrigation Engineers

Fertilizers. The twin objectives of fertilizing lettuce are production of crisp solid heads of marketable size and delay of bolting, since bolting destroys the market value of the head (**8**). It follows, therefore, that fertilizer practices must be designed to compensate the plant food deficiencies of the soil as well as to control growth of the plant. If the soil is kept in good physical condition by beneficial rotation practices, the problem is essentially one of determining the need, quantity, time of application and method of application of the three macro-elements—nitrogen, phosphorus, potassium. The amounts of these plant nutrients taken from the soil by a crop of lettuce are relatively modest when compared with those taken by most other crops (Table II). Generally speaking, experimental work with commercial

fertilizers has indicated that applications of nitrogen and phosphorus are necessary for the production of a satisfactory crop. In the semi-arid soils of the southwestern United States there is a natural nitrogen deficiency, and on alkaline-calcareous soil types the availability of phosphate is at a very low level. There is some question whether any benefit is to be obtained from application of potassium to many soils in the Southwest, most of which contain an abundance of this element.

After a thorough study of lettuce fertilization in Arizona, McGeorge, Wharton and Frazier (8) summarized the situation thus: " either nitrogen or phosphate alone will give profitable response, additional response will be obtained from combinations of the two, and still further improvement from a mixture of nitrogen, phosphate, and organic matter ". These investigators also produced convincing evidence that phosphate promotes early maturity while nitrogen delays it.

With the principles just discussed in mind, the quantities of fertilizer needed for various localities can be worked out. However, because of the variables involved, each farm presents a different problem, and as a rule general recommendations are valid only within moderate limits.

Experimental work by horticulturists and soil scientists shows that a profitable fertilizer response may be anticipated from all methods of application—broadcast, drill, side dressing, band and gas. However, there is little evidence to indicate which of these is the most efficient under all conditions or whether one method is suitable for all conditions. Actually, in practice most or all of the methods of application mentioned are used to produce the crop. Fertilizers that contain phosphates are usually broadcast or drilled on the fields before the beds are made. Part of the nitrogen may be included with the phosphate. Additional nitrogen may be applied later in a band or as side dressing, or it may be applied as ammonia gas dissolved in the irrigation water.

TABLE II[4]

COMPARISON OF LETTUCE WITH SEVERAL OTHER CROPS IN AMOUNT OF NITROGEN, PHOSPHORUS AND POTASSIUM REMOVED FROM THE SOIL IN POUNDS PER ACRE WITH GOOD ACREAGE YIELDS.

Element	Lettuce	Tomatoes	Corn	Sugar beets	Potatoes	Cotton
Nitrogen	47	100	95	115	125	65
Phosphorus (as P_2O_5)	7	35	35	45	35	25
Potassium (as K_2O)	117	175	70	145	170	50

Timing of fertilizer application is of considerable importance because it has been shown that the plants must have access to a continuous supply of nitrogen and phosphate fertilizers throughout the growth period. If the initial application is not broadcast or drilled, the fertilizer may be applied as a band[5] when the seed is planted or as a side dressing shortly after emergence. After the plants are thinned it is customary to apply nitrogen fertilizer as a side dressing (Fig. 2). If the temperatures are low another application of nitrogen several weeks before harvest maturity may

[4] Lettuce data from Lorenz and Minges (6); data for other crops from Romaine (10).

[5] Machines that will simultaneously shape the bed, plant the seed and distribute the fertilizer in the desired position have been designed.

FIG. 2. Lettuce field being cultivated after thinning. At this stage of plant growth a side dressing of nitrogen is very often applied.

be necessary. This may be made as a side dressing or in the form of ammonia dissolved in the irrigation water.

Irrigation. The importance of timely and proper application of irrigation water in the culture of lettuce cannot be stressed too much. Irrigation engineers and soil scientists have recognized this fact, and considerable research has been concerned with the amount of water necessary to produce the crop and the frequency with which it should be applied to secure maximum yields.

The basic requirement for good irriga-

tion practice is to have the land leveled to a certain grade, depending upon the soil type. All minor depressions and elevations should be smoothed out; otherwise, poor distribution of soil moisture may result in uneven stands and non-uniform maturity of the crop. Equipment has been devised that will accomplish this operation in a very efficient manner (Fig. 3).

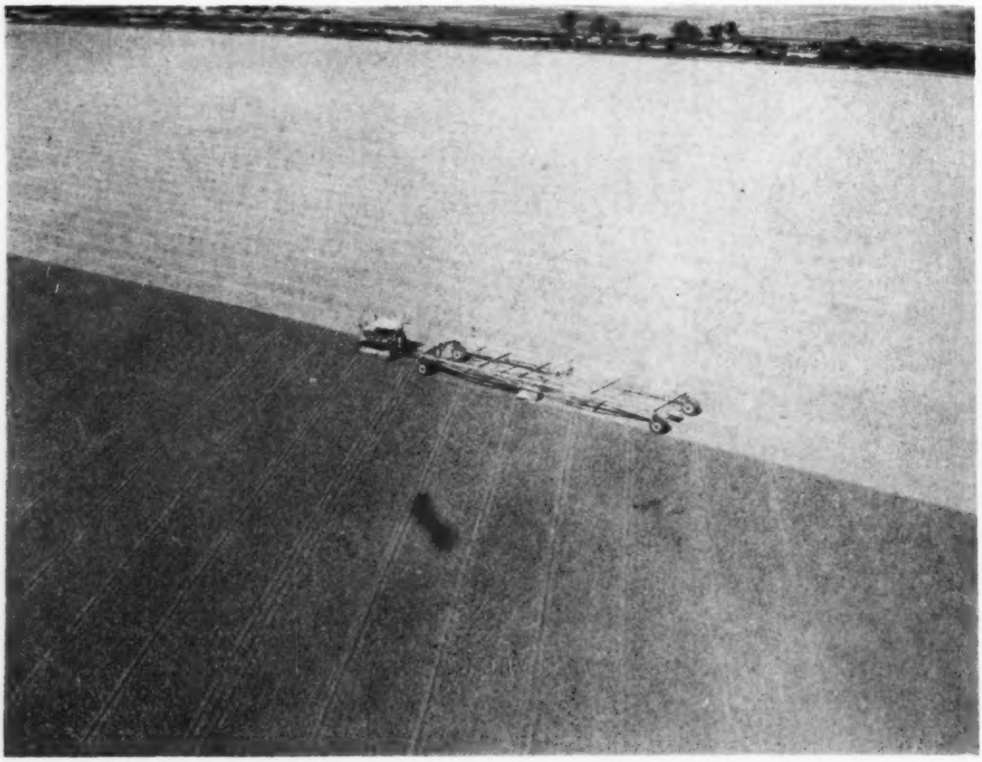


FIG. 3. Equipment used in preparing land for lettuce culture. The photograph shows a land plane employed to smooth the surface soil for irrigation.

As a rule the first irrigation is very heavy in order to thoroughly soak the seed bed and obtain even emergence of the young seedlings (Fig. 4). Thereafter, the rate and frequency of application should be largely governed by the soil moisture content. Lettuce has a small, shallow, compact root system. Irrigation water should be applied in a manner designed to maintain an adequate supply of available moisture in the root zone at all times. In the hot dry inland valleys where the crop matures during the late fall, winter and early spring, one and one-half to two acre-feet of irrigation water is normally required; for summer maturity, as in the Salinas Valley of California, one and one-half acre-feet is considered necessary to produce the crop.

Contribution of Agricultural Engineers

Harvesting Equipment. Like most other vegetables, lettuce requires an unusually large amount of hand labor to produce the crop. In order to reduce the labor requirements connected with harvesting, trailers and trucks have been designed that can go into the fields and

be loaded directly by the harvesters (Fig. 5). Many growers use a mechanical loader with a conveyor belt mounted on a truck (Fig. 6). It covers eight to ten beds and empties into a truck with baskets or a trailer drawn by a small tractor that moves down the field with the loader. The loader extends at right angles to the beds, and the harvesters walk directly behind the machine, harvesting the mature heads and placing them on the belt. Each man harvests the mature heads in the two rows nearest him.

For the most part harvesting methods and machinery have not been the outcome of organized research, but have been developed through the ingenuity and inspiration of growers in combination with a great deal of mechanical skill supplied by the personnel of local machine shops.

Packing Sheds. In the main lettuce-producing areas of the Southwest, most of the lettuce is packed for long-distance transportation in central packing sheds (Fig. 7). Considerable engineering research has gone into the development of a packing shed of efficient design and the equipment to operate it effectively. The design and equipment are in a continuous process of alteration as attempts are made to increase the efficiency of operations and decrease the labor costs. The packing-shed routine must be geared to production of a good product in an

FIG. 4. Irrigation of a lettuce field prior to emergence. This irrigation is usually very heavy (see text).

FIG. 5 (*Upper*). Harvesting of a lettuce field; the heads are tossed directly into the baskets on the trucks.

FIG. 6 (*Lower*). Harvesting of a lettuce field; showing the operation of a mechanical loader.

attractive package that retains some consumer appeal when it arrives in the terminal markets.

In most modern sheds, where lettuce is transported from the fields in trailers or baskets[6], the load is brought inside the shed. When raised on one side by a power lift, the trailers discharge their loads on an apron. The apron carries placed in bins by the side of the packers. When baskets are used, essentially the same procedure takes place, except that each basket has an individual hoist that raises it on one side, and the lettuce is trimmed directly out of the basket and placed within reach of the packers. In a modified version of this set-up, the trailers discharge their load on an end-

FIG. 7. A modern lettuce packing shed; packers on the left, trimmers on the right. The man in the suspended cabin in the center of the photograph operates the "snow plow" that pushes the lettuce from the conveyor within reach of the trimmers.

the lettuce within convenient reach of the trimmers who remove the old, dead and discolored leaves, and the product is less circular conveyor that carries the lettuce past the trimmers. Packers place heads of uniform size in a crate; after packing is completed, the crates are placed on a roller conveyor which rolls them to the lidding press and then into refrigerator cars.

Waste material is generally removed from the sheds by a continuous conveyor that operates within a trough between the trimmers and packers and extends

[6] Baskets are steel-framed containers, 3′ × 4′ × 7′9″. They have slatted sides and a solid bottom, and are equipped with four coasters so that they are easily maneuvered by hand. Trucks having a capacity of five baskets are used to haul the lettuce from the field. Some shippers use bevel-sided baskets, approximately the same size as the rectangular ones, but loaded six to each truck, lengthwise.

the full length of the building. The conveyor usually terminates in an elevator which dumps the material into trucks that haul it to cattle feeding yards.

Contributions of Refrigeration Engineers

Containers. The proper type and dimension of containers for transporting lettuce to distant markets have been a continuous and vexing problem during the entire history of the industry. Until relatively recent times, container research lagged behind other developments. Crushing and bruising resulted when too much pressure was applied by the lidder, and there have been many instances of drastic damage to the containers and contents in transit from improper loading.

Chiefly for the reasons just cited, the Western Growers Association joined forces with the U. S. Department of Agriculture in research aimed at bringing about some improvement in the container problem. After a year and a half of experimental shipping and testing, this unit came up with the WGA crate (designated No. 935 in the Container Tariff). This crate is deeper, wider and shorter than those previously in use. It will hold four or five dozen lettuce heads and remain within the one and five-eighths inch bulge regulation with much less bruising than similar containers. It is anticipated that this crate will become standard for the industry.

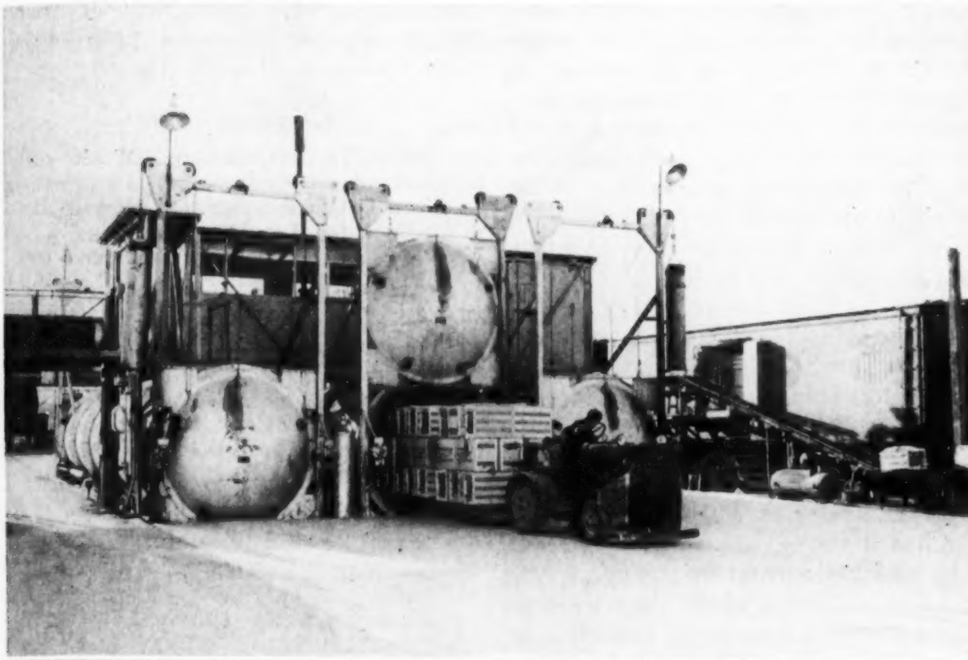
Iced Package. A fundamental step in the marketing of lettuce has been the development of the iced package. Where there is a lapse of ten to 15 days between the date of harvest and the time the consumer has access to the product, some method of keeping it fresh and crisp is necessary. The iced package, the refrigerator car and top-icing of the loaded car are answers to this problem.

The lettuce crate is lined with two strips of heavy waterproof paper which cover the bottom, sides and ends, and fold over the top. This paper lining protects the heads from mechanical injury, desiccation and dirt, and, in addition, tends to keep them cool and fresh. Three layers of heads are packed tightly in each crate (usually four or five dozen heads per crate), and cracked ice is placed between the layers and on top of the final layer before the paper is folded over and the lid applied. From ten to as much as 30 pounds of ice are used for each crate.

The quantity of ice necessary for each container and the manner in which it should be used for best results have been the subjects of much experimental work. For example, it has been found through appropriate shipping tests that ten to 15 pounds of ice per crate, under some circumstances, is more desirable than larger quantities. With the smaller amount of ice in the crate there is apt to be less ice bruising and water soaking of the outer head leaves; and, of course, the smaller amount is less expensive.

Vacuum Cooling. A recent development in preparing lettuce for long-distance transportation is the vacuum or " flash " cooling of the commodity before it is placed in refrigerator cars. This method is still in the experimental stage, but the results so far suggest that it may offer shippers certain advantages in reducing packing and shipping costs, as compared with the conventional ice-packed crate. Its ultimate commercial exploitation will depend primarily upon the condition in which the produce arrives in the terminal markets, and this point has not yet been satisfactorily determined.

The equipment needed for vacuum cooling is comparatively simple. Essentially, it consists of a steel tube or tunnel, 50 feet long and seven and one-half to eight feet in diameter, fitted at each end with pneumatically operated doors (Fig. 8). The tunnel is usually equipped



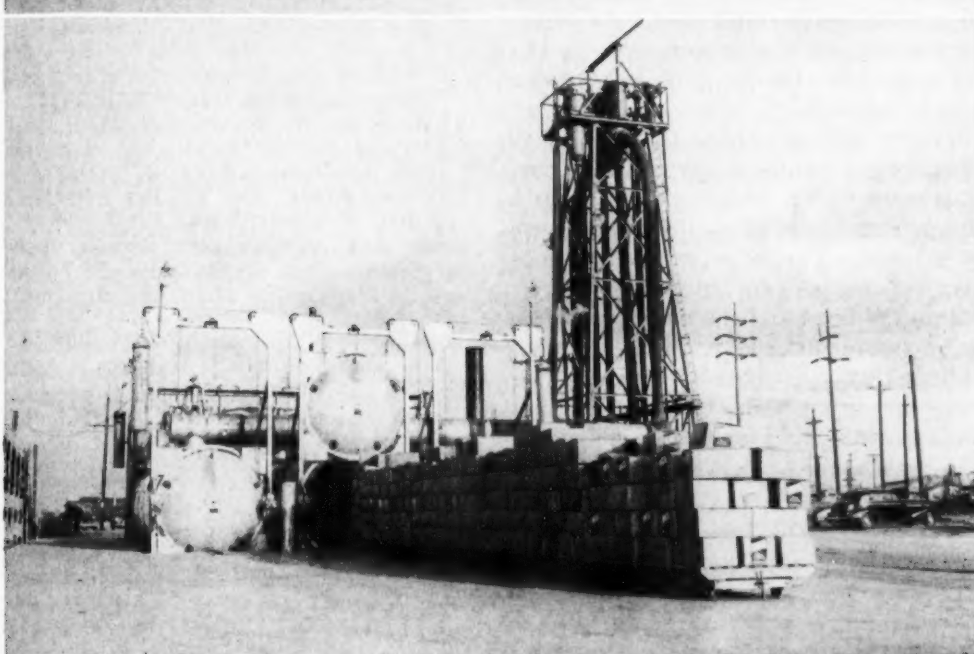


FIG. 8 (*Upper*). Vacuum cooling plant for lettuce. The special flat cars are withdrawn from the tunnel after cooling. This unit has three tunnels with a capacity of 35 carloads of lettuce per day.

FIG. 9 (*Lower*). Vacuum cooling plant for lettuce; showing flat cars loaded with cardboard containers.

with a track, on which specially constructed flat cars operate. Some means of rapidly reducing the air pressure in the tunnel completes the assembly. This can be accomplished in several ways, but for large scale vacuum cooling of produce, the method in general use is the steam jet system (3).

For vacuum cooling treatment the lettuce is trimmed and packed as usual but without addition of ice layers to the package. It is placed on the flat cars and is drawn into the tunnel (capacity, 200 crates) by motorized equipment. With present equipment it takes 15 to 25 minutes to produce a vacuum sufficient to cool lettuce to 32° F. As soon as the desired temperature is reached, the vacuum is released slowly, and the flat cars are then withdrawn from the tunnel at the opposite end from which they entered. The containers are placed immediately in pre-iced refrigerator cars. As stated previously, no ice is required in the package, and top-icing of the loaded cars is unnecessary.

Dewey (2) attributed the rapid rate of cooling of lettuce in vacuum to vaporization of water almost simultaneously throughout the head as the air pressure is reduced. The large ratio of surface area to volume for individual leaves within the head and the presence of free water between the leaves are additional factors that contribute to rapid cooling when the air pressure is reduced. Vacuum cooling opens up a number of possibilities, among which is the use of fiberboard containers as a substitute for the conventional wood crate (Fig. 9).

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Natural Crossing in Cotton[1]

The amount of natural crossing in cotton fields is of significance in current breeding methodology and in the development of new methods which attempt to make use of hybrid vigor. It is suggested that more critical methods of estimating the amount of natural crossing than those presently employed would be desirable. The possible advantages of obtaining estimates from segregating populations, rather than mechanical mixtures of contrasted stocks, are outlined briefly. The most generally important factor in natural crossing is the size of the effective bee population. A rapid method of measuring the relative activity of bees, involving distribution of finely powdered dye particles during flower visitation, and applicable in any field of cotton, is presented.

S. G. STEPHENS and M. D. FINKNER

The Significance of Natural Crossing

It has been known for some time that the seeds produced by any individual cotton plant in the field result from a mixture of self- and cross-pollination. The proportion of crossed seeds is known to vary considerably according to location and (probably) season. In recent years co-operative studies have been set up to sample a range of representative locations over several seasons throughout the U. S. Cotton Belt, under the leadership of D. M. Simpson, U. S. Field Station, Knoxville, Tenn. As a result of these studies more precise information is becoming available on the relative magnitude of natural crossing at various locations. Present evidence (**9**, **10** and unpublished) indicates that the proportion of natural crossing may be lower than five percent in some parts of Texas or higher than 50 percent in North Carolina and Tennessee. It seems likely that these great differences are due chiefly to differences in size of the effective bee populations. Of the various Hymenopteran species which may act as pollen vectors, bumble bees (*Bombus* spp.) seem to be most generally important (**2**, **6**, **8**).

The amount of natural crossing in cotton has considerable practical significance both with regard to current breeding practices and for the development of new breeding methods in the future. Until recently its importance has not been realized, and most workers have been concerned only in determining the extent of natural crossing in order to decide the degree of isolation necessary to avoid contamination of multiplication plots (**1**, **5**). It is probable, however, that the degree of natural crossing plays a more fundamental and perhaps unsuspected role in current breeding techniques. In developing new varieties of cotton the breeder attempts to extract superior lines from his breeding stocks. Following systematic testing the best lines are commonly bulked and multiplied for two or three years in increase blocks to provide seed for commercial planting. It will be evident that the

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composition of the " variety " finally released to the farmer will be dependent on the initial heterozygosity of the breeder's selections and the amount of natural crossing which has taken place during multiplication. It could vary between the following limits: (a) a mechanical mixture of different but more or less homozygous biotypes, (b) a hybrid swarm in which the identities of the original selections have been lost. In the latter case the combining ability of the lines included in the multiplication mixture and the amount of hybrid vigor retained during multiplication might be important, though perhaps unconsidered, factors in the success of the " variety ".

Not only is the degree of natural crossing of significance in connection with current breeding methods—it may be of importance in the development of new breeding techniques. If natural crossing may amount to 50 percent in some localities, the possibility of making practical use of it in the production of hybrid cottons becomes worthy of investigation. One possibility which has been suggested aims at the production of a pure hybrid F_1 population. This would involve the planting of a mixture of two parental strains carrying contrasting seedling marker genes, allowing the strains to intercross, and roguing out the non-hybrid seedlings (distinguishable by the marker) in the following generation. Since cotton is usually planted at a high seed rate and subsequently thinned to a stand in the usual farm operation, the production of an entirely hybrid population would appear to entail no practical difficulty per se. The chief practical drawback lies elsewhere, namely, in the large area required to produce the hybrid seed relative to the area growing the hybrid crop. Under present conditions it would appear that the hybrid seed produced by one acre would be sufficient to plant only 50 acres to a hybrid crop.

Another possibility which is being investigated (9) is the multiplication of mechanical mixtures of strains under conditions of high natural crossing. The strains included in the mixture are chosen on the basis of good combining ability which usually results from combinations between rather widely different genotypes. This method clearly represents a conscious extension of current breeding methods in which rather closely related strains are mixed prior to multiplication. The limitations of this method are not clearly defined. It is not yet known how widely different the parental strains may be without impairing a necessary degree of uniformity in the final product, nor whether the amount of hybrid vigor retained after several generations of multiplication under conditions of outcrossing is sufficient to produce a significant increase in yield over standard agronomic varieties.

The above considerations show that a rather detailed knowledge of the factors affecting natural crossing in cotton may be of considerable importance in evaluating current breeding methods and is certainly fundamental to the logical development of new techniques.

Methodology

The method commonly used for determining the proportion of natural crossing is a standardized procedure developed by Simpson (10). A mixture of two stocks, one carrying a dominant " red seedling " marker gene, *R*, and the other its recessive allele, *r*, (" green seedling ") is planted in an isolation plot. The mixture is composed of 90 percent *RR* and 10 percent *rr* plants laid out according to a standard systematic plan. The open pollinated bolls of all *rr* plants are harvested and the seed germinated. The proportion of heterozygous red seedlings (*Rr*) obtained is considered a measure of the proportion of crossing which has taken place. It should be noted that the proportion of *Rr* seedlings

obtained is only a relative measure of crossing—the actual amount of crossing may be greater, since, for example, with random bee visitation and equivalent flower production, ten percent of the crossing should involve inter-se $rr \times rr$ combinations indistinguishable from selfs.

Although this method has the advantage of simplicity and has been of great value in demonstrating gross differences in the extent of natural crossing in various parts of the Cotton Belt, it cannot be considered accurate without further checking by independent methods. If the estimates so far obtained are applicable only to the experimental stocks used and to the conditions under which the tests are carried out, they will necessarily be of limited value. Until the possibility of various shortcomings in the method have been checked, the general validity of the estimates obtained remains questionable. Points which require further investigation may be considered briefly here:

Specific Stock Differences. The results obtained by the present method are strictly applicable only to the two standard stocks employed. The results could be biased by any or all of the following possibilities:

(a) Marked differences in flower production or differences in pollen abundance between the RR and rr stocks. The amount of Rr seed produced is not independent of the relative proportions of R and r pollen available.

(b) Non-coincidence in flowering period. For instance, if the rr parent commenced flowering earlier in the season, the early bolls would contain no Rr seeds and the degree of outcrossing would be underestimated.

(c) Differences in time of anthesis. The pollen from anthers which burst earliest in the morning will have the greatest chance of effecting fertilization.

(d) Differences in floral structure. The size of the flower and relative positions of anthers and stigmatic lobes may affect the amount of crossing.

(e) Differential pollen germinability and/or pollen tube growth rate.

Reliability of Data Collected from Small Isolated Plots. All upland cottons grown commercially in this country carry the recessive (r) gene. Consequently the present method of measuring natural crossing must be carried out in a small plot isolated from the immediate neighborhood of other cotton fields, since the method depends on reducing the possibility of $rr \times rr$ crossing to a minimum. This means that the effective bee population which visits the isolated plot may be different from that which is operating in other fields and raises the question as to whether the amount of crossing observed is at all representative of the region in general. On the one hand, it is quite possible that a small isolated patch of cotton may be more thoroughly worked over than a large field. On the other hand, it is possible that a small patch may be overlooked when more flowers are available elsewhere. Theoretically this objection could be removed by discarding the dominant (R) marker stock in favor of a suitable recessive. It would then be necessary to distribute only a few plants of the recessive sock in a regular field planting and score their open pollinated progenies. In practice, unfortunately, no suitable recessive markers are as yet available, since the typical upland genotype found in economic varieties already includes most of the nondeleterious marker genes.

It will be evident from these brief considerations that in order to obtain a more critical evaluation of the factors

involved in natural crossing, two lines of investigation would be appropriate. The first of these is a critical and comparative study of stock differences in respect to natural crossing, and an analysis of the factors responsible for these differences. An investigation of this type is already in progress at this Station and will be reported in detail elsewhere. The results indicate clearly that differences between stocks are not negligible and that most of the possible sources of bias which have been outlined above are of practical significance. A second line of investigation which would seem to be profitable is the development of methods of measuring natural crossing which are less dependent on stock differences and hence of more general applicability. The remainder of this paper is concerned with a preliminary survey of the possibilities in this latter type of investigation.

TABLE I

PERCENTAGE OF HETEROZYGOSITY EXPECTED IN SUCCESSIVE GENERATIONS UNDER A SYSTEM OF 50 PERCENT OUTCROSSING, COMMENCING (a) WITH AN F_1 POPULATION (b) WITH AN EQUAL MIXTURE OF TWO PARENTAL STOCKS

	Number of partially outcrossed generations					
	0	1	2	3	4 . . .	n
(a)	100	50	37.5	34.4	33.6	33.3
(b)	0	25	31.3	32.8	33.2	33.3

Neutralization of Stock Differences in Estimating Natural Crossing

It has been pointed out that estimates of natural crossing based on a mixture of two homozygous stocks are of doubtful general validity unless supported by independent evidence. It would be an advantage to have a method of measuring natural crossing in which stock differences could be neutralized and the consequent sources of bias reduced. From the genetic point of view the sources of bias are due to genetic differences between stocks which effect their crossability. These fall into three categories:

(1) Chance associations of genes.
(2) Genes linked with the seedling marker employed.
(3) Pleiotropic effects of the markers themselves.

The first of these sources of bias can be neutralized by using estimates from segregating populations instead of mechanical mixtures of homozygous stocks. It has been shown previously (11) that the proportion of heterozygotes expected in successive generations of a partially outcrossed population can be derived from the formula,

$$h = 1/2\ ((1 - k)\ h' + k)$$

where h is the proportion of heterozygotes in the current generation, h' the proportion in the preceding generation and k the proportion of outcrossing. As an example, the proportions of heterozygotes expected in successive generations when k = 50 percent are shown in Table I. Conversely when h and h' are known, k can be calculated from the data. Theoretically, therefore, any population segregating for a suitable seedling marker could be grown in isolation, the number of heterozygous individuals recorded, and the whole population allowed to outcross *inter se*. The seed could be harvested in bulk and adequate samples germinated to determine the proportion of heterozygotes in the fol-

lowing generation. If heterozygotes, *Aa*, were not phenotypically distinguishable from homozygous dominants, *AA*, but were produced according to Mendelian expectation, their numbers could be estimated as the difference, $(AA + Aa) - aa$, in each generation. By this method characters affecting crossability—other than those attributable to pleiotropic effects or linkage—should be distributed at random over the population and hence should not influence the relative transmissions of the marker genes.

TABLE II

METHOD OF ESTIMATING THE PROPORTION OF NATURAL CROSSING FROM THE PROGENY RESULTING FROM AN ISOLATED BUT OPEN POLLINATED F_2. THE FAMILY WAS SEGREGATING FOR A SEEDLING MARKER GENE, *R*

Sample	Frequencies of genotypes in progeny (germination: 96%)				
	$RR + Rr$	rr	Total	χ^2	k
1	755	388	1143	0.0119	28.4%
2	302	163	465	0.1888	19.6%
3	723	370	1093	0.0296	29.2%
Total	1780	921	2701	0.2303	27.2%

$(P_{(2)} = 0.80 - 0.90)$

Estimation of proportion of natural crossing:

Proportion of heterozygotes in F_2

$$h' = 0.50$$

Proportion of heterozygotes in progeny

$$h = \frac{1780 - 921}{2701} = 0.3180$$

Substituting in formula,

$$h = 1/2\,((1-k)h' + k),$$
$$k = 0.272 \text{ or } 27.2 \text{ percent.}$$

In practice this method is not sensitive enough to provide precise estimates of the proportion of natural crossing, although the estimates obtained should be free from bias. This is illustrated by the example given in Table II. The material used was an F_2 population obtained by selfing a hybrid between two races of *G. arboreum* (Asiatic cottons). The population of approximately 250 plants was segregating for a red seedling marker, *R*, in the proportion 3 $(RR + Rr) : 1\ rr$. It was grown in isolation from other interfertile species and left to open pollination. The whole plot was harvested, the lint removed from the seeds by ginning, and three random samples of seeds drawn for progeny tests. The results presented in Table II showed no evidence of heterogeneity between samples so that an estimate of the proportion of natural crossing could be made from the combined data. The proportion of heterozygotes (h') in the F_2 was taken as 50 percent (the Mendelian expectation). The proportion of heterozygotes (h) in the progeny resulting from open pollination was calculated as the difference, $(RR + Rr) - rr$, since homozygous dominants and heterozygotes were not readily distinguishable. Substituting these values in the appropriate formula gave a value of k (proportion of outcrossing) = 27.2 percent. However, although the data show no evidence of heterogeneity between samples, it should be noted that an estimate based on Sample 2 alone would have given a value as low as 19.6 percent. The insensitivity of the method is chiefly due to the fact that the phenotypic compositions of the progenies of only 25 percent of the F_2 plants (*i.e.*, those with the genotype *rr*) are affected by the amount of natural crossing which takes place—see Table III. All plants in the progenies from *RR* parents will carry *R* irrespective of whether they result from selfing or outcrossing. Also progenies from *Rr* parents will be composed of 75 percent $(RR + Rr)$ and 25 percent *rr* under either system, since with outcrossing the chances of *Rr* being crossed by *RR* and *rr* plants should be equal (Table III). The degree of outcrossing affects the composition of progenies only from *rr* parents which will vary between the limits of 100 percent *rr* (entirely selfed) and 50 percent *rr* (completely out-

crossed). Clearly it would be simpler and more accurate to harvest only the progenies of *rr* plants, in which case the proportion of natural crossing should be exactly double * the proportion of *Rr* seedlings in the progeny, *i.e.*, the upper limit of 100 percent outcrossing corresponds to an upper limit of 50 percent *Rr* (Table III). In addition, the variation in the compositions of the progenies of individual *rr* plants could be used to measure the precision of the estimate of natural crossing.

TABLE III

THE EXPECTED COMPOSITION OF THE PROGENIES OF AN F_2 POPULATION HETEROZYGOUS FOR *R* AND *r* UNDER TWO BREEDING SYSTEMS: (a) COMPLETELY SELFED (b) COMPLETELY OUTCROSSED

Composition of F_2	Composition of progenies			
	(a)		(b)	
	% *R*	% *r*	% *R*	% *r*
25% *RR*	100	0	100	0
50% *Rr*	75	25	75	25
25% *rr*	0	100	50	50
Average	62.5	37.5	75	25

It is believed that this method, which utilizes a segregating population instead of a mechanical mixture of homozygous stocks, will provide an improvement in the methodology of measuring natural crossing. In its simplest form, as outlined above, it provides a means of obtaining estimates which are free from bias due to stock differences. It has another advantage in that, by elaborating the technique a little, the effects of bias due to pleiotropy and/or linkage also can be measured. Since any isolated population which is segregating for a suitable marker gene can be used to estimate the proportion of natural crossing, it is clear that a population which is segregating for several independent marker genes can be used to obtain several independent estimates simultaneously. Provided that none of the markers employed has pleiotropic effects on, or is linked with other genes affecting, crossability, the various estimates obtained should not differ significantly. Aternatively, if significant differences are found, it should be possible to trace these differences to the specific marker genes concerned. An experiment which will provide a population segregating for seven independent markers is now in progress at this Station.

Although it seems likely that the pleiotropic effects of marker genes may have relatively little effect on estimates of natural crossing, they cannot be ignored at the present time. The evidence currently available in Upland cottons seems to be conflicting or non-critical. With regard to the *R* (red seedling) marker, which until now has been used almost exclusively in measuring natural crossing, Cain (unpublished) found in Texas a strong negative association between the *R* gene and seed production. Since segregating populations were employed in his experiment, it seems that his results can be attributed only to pleiotropic effects of the *R* gene under Texas conditions. On the other hand, Turner (unpublished) in Georgia finds no significant differences in the seed production of comparable *R* and *r* lines. Differences in seed production may or may not imply differences in flower production which would be significant in determining natural crossing. Perhaps of more immediate interest in this connection are the results of Hancock (4) which indicated that *R* pollen germinated more rapidly than *r* pollen on the artificial culture medium he employed. However, since the pollens were not otherwise iso-

* This, of course, would be strictly true only when the frequency of the F_2 classes accorded with Mendelian expectation. The normal procedure would be to calculate the amount of natural crossing on the basis of actual rather than the expected frequencies.

genic, the difference observed is not strictly attributable to the effects of the *R* gene. Preliminary experiments at this Station (Finkner, unpublished) have shown that a "Virescent Yellow" stock (carrying the recessive gene, *v*) is highly outcrossed, and since its high crossability is transmitted to the virescent yellow segregates in its second generation outcrossed progeny, it seems likely that a pleiotropic effect of the *v* gene is responsible. The nature of the supposed pleiotropic effect is under investigation.

ferent. The effective bee population may be defined as the ratio of the number of bees to the number of cotton flowers in a given area: the higher the ratio the greater the amount of natural crossing expected up to the limit where the number of bees is sufficient to completely pollinate all flowers. It seems likely that fluctuation in this ratio in respect to season, time and location is the most generally important factor in determining the amount of natural crossing. It would be an advantage to have a rapid method of estimating it on a quantitative basis which could be applied in any population of cotton plants irrespective of its genetic composition.

TABLE IV

DISTRIBUTION BY BEES OF METHYLENE BLUE PARTICLES FROM A SINGLE DUSTED FLOWER IN EACH OF TWO SPECIES OF GOSSYPIUM

(8-2-50)

(a) *G. arboreum* (Asiatic)

*Distance from dusted flower (ft.)	0–3	-6	-9	-12	-15	Total
Nos. of flowers collected	12	6	5	5	12	40
Nos. of flowers with dye particles	8	4	2	2	2	18
Percentage with dye particles	67	67	40	40	17	45

(b) *G. hirsutum* (Upland)

*Distance from dusted flower (ft.)	0–3	-6	-9	-12	-15	Total
Nos. of flowers collected	4	5	4	6	7	26
Nos. of flowers with dye particles	4	5	3	5	4	20
Percentage with dye particles	100	100	75	83	57	77

*These distances represent distances along the same row on either side of the plant bearing the dusted flower. Plants spaced 18 inches apart in the row.

The Effective Bee Population in Relation to Natural Crossing

It has been shown that possible sources of bias in the estimation of natural crossing can be avoided if segregating populations are used in place of mechanical mixtures of stocks. However, in practice these methods can be employed only in relatively small scale isolated plots: small scale because the growing and scoring of a large number of progenies is time-consuming, and isolated because the genetic composition of the population must be known. Such tests, though accurate, are limited in scope, as the results are not necessarily applicable to general field conditions where the effective bee population may be very different.

Preliminary Studies. A pilot experiment carried out in 1950 showed that an indication of the effective bee population could be obtained very easily by placing a finely powdered dye in a newly opened flower and allowing the bees to distribute the dye particles to other flowers in the neighborhood. Methylene Blue was found to be a suitable dye, as the bees did not avoid the "dusted" flower and the dye particles were readily visible under a hand lens on the corollas and stigmas of neighboring flowers on the following day. The results (Table IV) and obser-

vations from this experiment, carried out with two species of cotton growing in the same field, led to the following tentative conclusions:

(1) Dye particles can be carried to flowers at least 80 feet from the dusted flower.

(2) As the distance from the dusted flower increased, both the proportion of flowers carrying the dye particles and the amount of dye particles per flower decreased. This rather uniform distribution of particles from a focal center suggests that many bees were working the flowers and that, on the whole, they worked from flower to flower in the immediate neighborhood. A preponderance of long zig-zag flights would not have given the same picture. This agrees with Allard's observations (2).

(3) In the *hirsutum* (Upland) population very few flowers in the near neighborhood of the dusted flower received no particles, whereas the *arboreum* (Asiatic) flowers were worked less extensively.

Method of Estimating the Effective Bee Population. It will be evident that both the distance to which dye particles are carried and the proportion of flowers which receive the particles will be determined by the effective bee population in the area. However, the distance is dependent also on the number of particles present initially at the focal center. As the bees move from the center it is to be expected that they will lose the dye particles they carry to flowers visited en route. The observed distance is, therefore, only a minimal distance, limited by the amount of dye available. A better estimate of the effective bee population is the proportion of flowers receiving dye particles at a relatively short distance from the dusted flower. Based on the data given in Table IV, a standard procedure was adopted—the anthers of a single flower were dusted with dye particles a 8:00 A.M., and on the following morning day-old flowers from the first 12 plants in the same row on either side of the plant bearing the dusted flower were collected and scored for the presence of dye particles. The percentage of flowers receiving dye particles should be proportional to the number of bees visiting the area and inversely proportional to the number of flowers available (*i.e.*, the greater the number of bees, the higher the chance; the greater the number of flowers, the lower the chance that the dusted flowers will be visited). The percentage of flowers receiving dye particles should, therefore, be closely correlated with the effective bee population as defined previously. It will remain constant only if the ratio of bees to flowers remains constant.

Temporal Fluctuations in the Effective Bee Population. Fluctuations in the effective bee population were studied in 1951 in two cotton fields situated about one quarter of a mile apart at McCullers Experiment Station, N. C. Three sampling areas were studied in each field at approximately weekly intervals during the month of August—this included the period of maximum flower production. The sampling plan and orientation of the fields with respect to other crops are shown in Figures 1 and 2. It will be noted that Field D was bordered on three sides by woodland, with tobacco (the only insect-pollinated crop in the neighborhood) on the fourth side. Field S was more openly situated with roads on three sides and peanuts bordering the fourth side. Peanuts and tobacco were the only flowering crops in the neighborhood. Field D contained an unselected assortment of interspecific hybrids (Upland × Egyptian progeny rows): ninety percent of Field S was planted with Upland intervarietal hybrids with one small

patch of Asiatic cotton (represented by sample area " S1 " in Figure 2).

The results obtained from five sampling periods at each of the six sampling areas are presented in Figure 3. By chance all sampling periods coincided with warm dry conditions, with the exception of the third period (August 10) during which there was heavy rain. Also the dusted flower in sample area S2 was lost at this time so that no data were obtainable. In Figure 3 the total number of flowers collected at each sampling is indicated by the height of the column: the height of the solid black portion of the column indicates the number of flowers containing dye particles. The figure at the top of each column is the percentage of flowers containing dye particles.

It can be seen that with the exception of the Asiatic cottons (S1) the sampling areas show a similar relationship between the number of flowers produced and the number containing dye particles. At successive sampling periods flower production rises to a maximum and then decreases toward the end of August. Over the same time interval the number of flowers with dye particles tends to decrease. As a consequence the proportion of flowers with dye particles is lowest during the maximum period of flowering and highest at the beginning and end of the flowering period. This would suggest that the number of bees working the flowers did not keep pace with increasing flower production, *i.e.*, the flowers were less thoroughly worked during the peak of flower production.

A very different situation is presented by the Asiatic samples in S1. Taking the data at face value it would seem that the bees did not visit the flowers in appreciable numbers until after the maximum period of flowering had passed. This might indicate either that the population of bees which visited the Asiatic flowers was different from that which

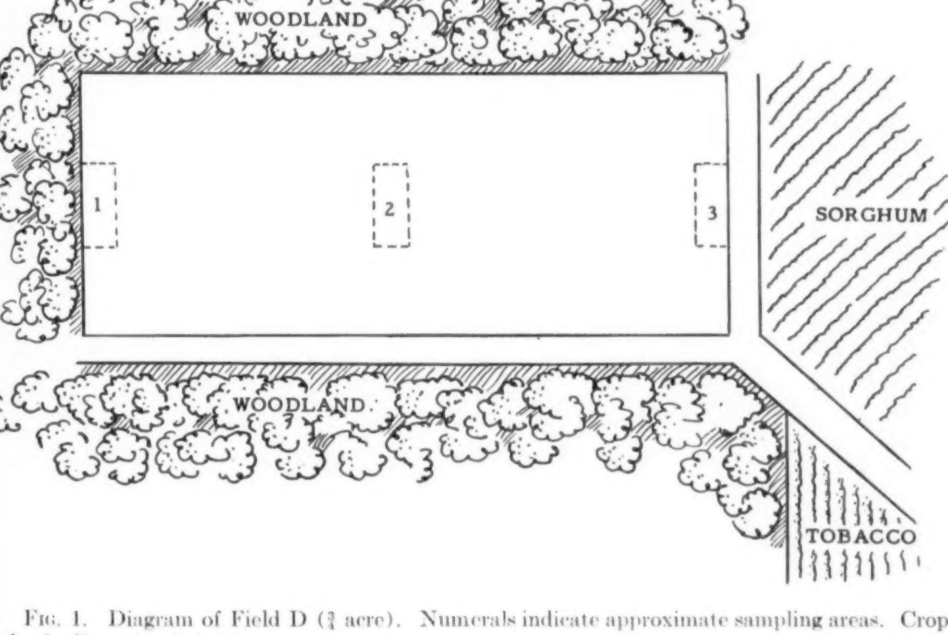

FIG. 1. Diagram of Field D (¾ acre). Numerals indicate approximate sampling areas. Crop: Upland × Egyptian hybrids.

visited the Upland flowers in the same field, or that the same population was involved but preferred Upland flowers, switching to Asiatic flowers only when the former became scarce. Actually field observations during the sampling periods confirmed neither of these interpretations. At no time was there any obvious difference between the numbers of bees visiting the two species, and in the border region they appeared to pass from one species to the other indiscriminately. It was noted, however, that the bees rarely entered the Asiatic flowers but confined their attention almost exclusively to the extrafloral nectaries at the base of the bracteoles. It may be that the bees attempt to enter the (smaller) Asiatic flowers only when the (larger) Upland flowers are becoming scarce. At all events it appears that the bees exhibit preferential behavior when offered the choice of Upland and Asiatic flowers. Furthermore, this preferential behavior almost certainly influences the amount of natural crossing in the two species, as shown by the data in Tables II and IV. In Table II the best estimate of natural crossing in an Asiaic cotton population was found to be 27 percent—approximately half that obtained in Upland cottons in successive seasons at the same station (Finkner, unpublished). In Table IV also the data show that the proportion of Asiatic flowers receiving dye particles was little more than half that obtained with Upland flowers growing in an adjacent plot.

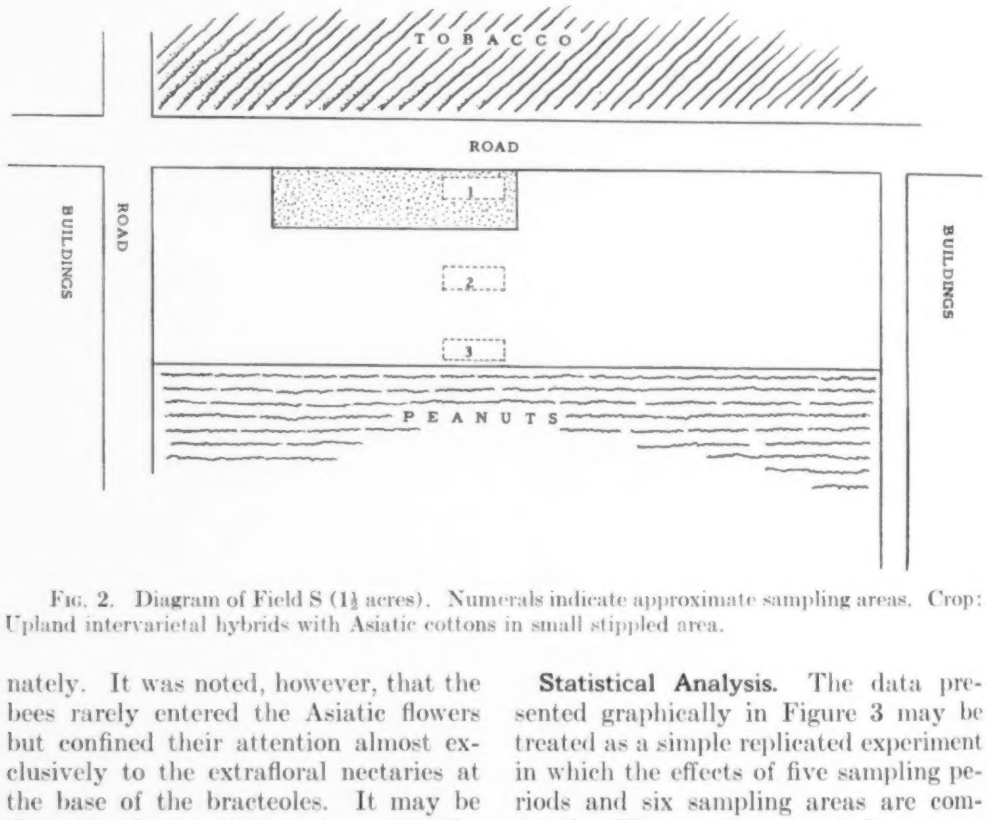

FIG. 2. Diagram of Field S (1½ acres). Numerals indicate approximate sampling areas. Crop: Upland intervarietal hybrids with Asiatic cottons in small stippled area.

Statistical Analysis. The data presented graphically in Figure 3 may be treated as a simple replicated experiment in which the effects of five sampling periods and six sampling areas are compared. The percentages of flowers receiving dye particles in each sample cannot be directly subjected to an analysis of variance, since they will have different variances and hence will be determined with different amounts of precision (7). However, the percentages may be converted to degrees, making use of the angular transformation tables given

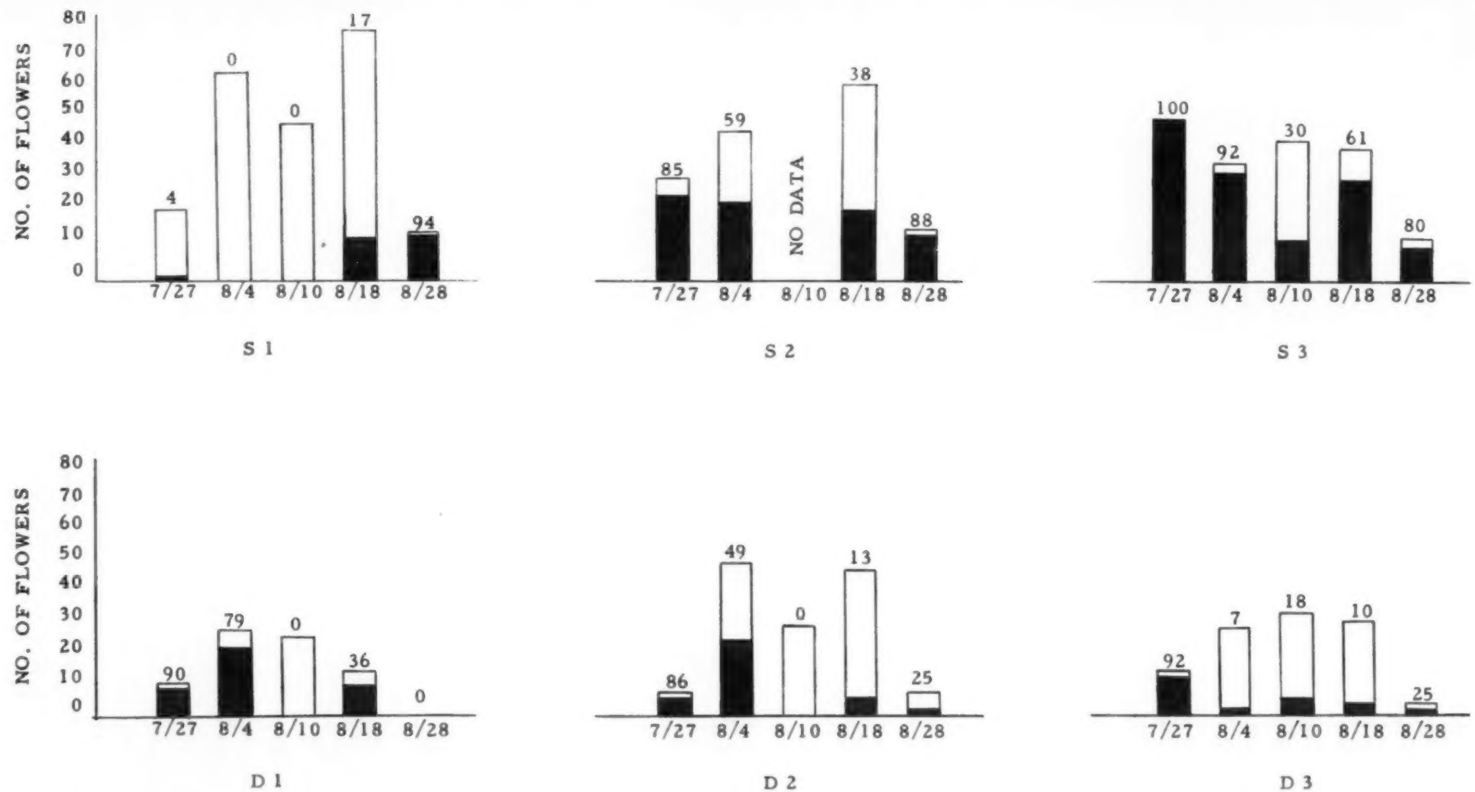

FIG. 3. Diagram showing the proportions of flowers receiving dye particles in each of the six sampling areas shown in Figures 1 and 2. The height of each column is proportional to the total number of flowers produced at each sampling period: the solid portion of each column represents the number of flowers receiving dye particles. Figures at the foot of each column give the date of sampling while figures at the head of each column indicate the percentage of flowers receiving the dye particles.

by Fisher and Yates (3). On the angular scale the variance is dependent only on the size of the sample, and the standard analysis of variance methods may be applied.

An analysis of variance of the transformed data is given in Table V. It will be noted that a value for the missing sample in S2 on August 10 has to be substituted with a consequent loss of one degree of freedom in computing the error variance (12). The analysis confirms what is already apparent in Figure 3, namely, that there are two major sources of variation, one associated with sampling period and the other with differences between the Asiatic and Upland samples in Field S. Differences between fields, between sampling areas in Field D and between Upland sampling areas in Field S are insignificant.

General Implications. From the limited data presented above it seems probable that the effective bee population, as defined above, can vary considerably during the flowering period and that it may be further modified by the discriminatory habits of the bees when they have a choice of flowers available. The possibility that they discriminate between varieties as well as between species (as indicated here) must be borne in mind. However, the most important feature brought out by the data is the implication that the number of bees does not keep pace with the number of flowers available, so that the flowers are worked less effectively during the flowering peak. Under certain conditions this could provide an upper limit to the amount of natural crossing. A decrease in an originally large effective bee population does not, of course, necessitate a corresponding decrease in natural crossing because, of the repeated visitations which may occur, only one (the first) may be of significance in effecting cross-fertilization. Conversely the effective bee population may be small and insufficient to produce many " repeat " visitations, and in that case any rapid increase in the number of flowers available would be likely to result in an appreciable reduction of natural crossing. The provision of a supplementary source of bees during the peak of the flowering period (9) may provide a solution to this problem.

TABLE V

ANALYSIS OF VARIANCE OF PERCENTAGE OF FLOWERS RECEIVING DYE PARTICLES IN TWO FIELDS (TRANSFORMED DATA)

Variance due to	D.F.	Sum of squares	Variance	"F"
Sampling periods	4	7981.9233	1995.4808	4.3530*
Sampling areas				
Field D *v.* Field S	1	1036.0563	1036.0563	2.2601
Within D	2	9.1960	4.5980	....
Within S				
Asiatic *v.* Upland	1	3814.8963	3814.8963	8.3218**
Within Upland	1	378.2250	378.2250	....
All areas	5	5238.3736	....	....
Error	19#	8709.9797	458.4200	
Total	28	21930.2017	....	....

#One degree of freedom lost in substituting missing sample.
*Significant at 5 percent level.
**Significant at 1 percent level.

Conclusions and Summary

1. The object of this paper has been to point out the significance of natural crossing in current breeding methodology and its importance to any logical development of new breeding techniques. It is believed that its importance is sufficient to warrant the adoption of more critical methods of quantitative estimation. Two possible lines of investigation which may lead to the improvement or amplification of current methods have been outlined briefly and illustrated with the rather limited data at present available.

2. It has been suggesed that isolated but open pollinated populations, segregating for several suitable marker genes, may provide a more suitable method for estimating the degree of natural crossing than mechanical mixtures of contrasted homozygous stocks. The advantage lies in the possibility of neutralizing various sources of bias (chance stock differences, linkage and pleiotropy of the marker genes employed) which may influence the apparent amount of crossing.

3. It has been pointed out that the effective bee population, defined as the ratio of the number of bees to the number of flowers in a given area, is the most generally important factor in determing natural crossing, and that a rapid method of estimating it which could be applied to any field of cotton, irrespective of its genetic composition, would be advantageous. A method which involves the distribution of a finely powdered dye by the bees during flower visitation is presented. It appears that the effective bee population may be lowest during the period of maximum flower production and that the bees exhibit preferences when offered a choice between flowers of two species of cotton.

4. The possible significance of these findings in natural crossing is considered briefly.

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A Pharmacognostic Study of Piscidia Erythrina[1]

The bark and wood of the root and stem of this West Indian tree have long been used by the natives of the Antilles as an analgesic, and their several physiological effects have found some use in modern medicine.

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History

Piscidia Erythrina L., more commonly known in the United States as " Jamaica dogwood ", is a tree belonging to the Family Leguminosae, the taxonomic characteristics of which were first described in **1753** by Linnaeus (1) as *Erythrina piscipula* L. Later in his *Systema Naturae*, Linnaeus placed this species under his genus *Piscidia* and revised its description (2). It is more fully described by Sargent (3) under the name *Ichthyomethia Piscipula* Hitchcock[3]. It is also found in the literature under the scientific terms *Piscidia piscipula* Sargent (3) and *Piscidia Carthaginensis* Jacquin (3) and under the common names of " bois à enivrer ", " bois ivrant " (4), " écorce de bois de chien ", " Jamaica dogwood bark ", " mulungú ", " murungú " (5), " fish-poison tree " (6), " bois enivrant " (7), " Jamaica fish-fuddle tree " (8), " fish-catching coral tree " (9), " guana hedionda " (Cuba), " palo de zope ", " zopilocuave " (El Salvador), " flor de papagallo ", " cocinte ", " javín ", " haabí ", " haabin ", " chijol " (México), " ventura ", " dogwood ", " fish poison " (Porto Rico) and " barbasco " (Venezuela) (10).

It grows in the West India Islands (6), especially in Jamaica and Martinique (7), and it has been found in Florida, Texas, southern Mexico and the northern regions of South America (6).

The root bark of *P. Erythrina* has been used by the natives of the Antilles for a great many years as an analgesic and as an agent for anesthetizing fishes, as was recorded in **1722** by the Dominican Jean Baptiste Zabet (especially in St. Vincent) (5).

In **1794** Barham pointed out in his *Hortus Americanus* that he had used the bark of this drug as an astringent tonic in the treatment of ulcers (11). In **1830** the English physician Hamilton, who lived in the Antilles, recommended this drug (5); and later, in **1884**, he studied the drug after having tried it on himself successfully against tooth neuralgia, and attributed to it very active narcotic and anesthesic properties (11).

The first chemical investigation of *P. Erythrina* was reported in **1883** by Hart (12) who obtained a nearly colorless crystalline substance from the fluid-extract prepared from the root bark by Parke, Davis and Co. The substance melted at 192° (uncorrected), and the

[1] An Edwin L. Newcomb Memorial Award Essay in Pharmacognosy.

[2] The author, whose address is Elias de la Cruz 15, Santiago, Chile, gratefully acknowledges the generous supply of bark, leafy stems and other parts of *Piscidia Erythrina* plants donated for this investigation by The Essex Research Foundation.

[3] Garden and Forest **4**: 472. 1891.

elementary analysis gave the formula $C_{29}H_{24}O_8$. He called it "piscidia"[4] and considered it responsible for the poisonous properties of the fluidextract.

In 1898 Berberich (13) published the results of a proximate analysis of the bark of *P. Erythrina* and those of a special search for the active principle "piscidia". He used the Hart's method for the extraction and stated that the crystals separated by him possessed all the properties assigned to "piscidia" by Hart.

In 1901 Freer and Clover (14) studied the root bark of *P. Erythrina* and found that Hart's piscidia is a mixture of two very distinct bodies, one $C_{23}H_{20}O_7$ m.p. 201°, and the other $C_{22}H_{18}O_6$ m.p. 216°, the former being in great excess. They also isolated a number of crystalline substances, among them piscidic acid, $C_{11}H_{12}O_7$ m.p. 185°.

In 1919 Pittenger and Ewe (15) studied the chemistry of the drug and obtained the same results obtained by Hart and Berberich.

In 1934 Danckwortt and Schütte (16) reported the results of an exhaustive chemical investigation of the drug sold as "Cortex Piscidiae Erythrinae". Among the various substances they found was a water-soluble glucoside of saponin character.

In 1944 Russell and Kaczka (17) studied chemically the root bark and the root wood of *P. Erythrina*, isolating rotenone and a new compound "ichthynone" $C_{23}H_{20}O_7$ m.p. 203–204°.

In 1948 Costello and Butler (18) studied for the first time the chemistry and pharmacology of the stem bark of *P. Erythrina* which had first been submitted to Dr. H. W. Youngken[5] for pharmacognostic identification and had been found to be authentic. The chemical analysis was carried out for the purpose of tracing the potent substance with a view to isolation.

In 1948, Budge, Coleman and Robertson (19) reported the results of their experiments on the structure of piscidic acid (dibasic acid) $C_{11}H_{12}O_7$, this being the best defined chemical constituent of *P. Erythrina*, first isolated and examined by Free and Clover (14).

The earliest physiologic researches on the drug appear to have been done in 1880 by Dr. Isaac Ott (9) and by Nagle (20). Both found that it has narcotic properties, that it causes dilatation of the pupils, that it increases secretion of sweat, and that it causes rise of blood pressure. They compared the action of morphia and piscidin and said that they are somewhat similar.

In 1916 Delzell, Burman and Pilcher (21, 22) found that Jamaica dogwood lowers the amplitude of the contractions of the excised intestine of rabbit and of the excised uterus of guinea pig.

In 1919 Pittenger and Ewe (15) studied the standardization of the drug by chemical and physiological methods and reported that only the physiological method is useful for the purpose. The method employed was the same as that for standardization of cannabis, producing incoordination and ataxia similar to that produced by the latter, the hypnotic effect being approximately one-seventeenth as great as in cannabis.

In 1932 Drake and Spies (23) studied the toxicity of certain plant extracts on goldfish and found that 1 ml. ext. (from 0.2 gm. plant material) per l. of *P. Erythrina* caused the death of goldfish in less than 100 min.

In 1936 Hauschild (24) reported that the amorphous yellowish substance obtained from the petroleum ether extract of commercial *P. Erythrina* bark is toxic for fish and for warm-blooded animals, strongly toxic for rats and rabbits when

[4] Some authors have referred to this substance as "piscidin" or "piscidine".

[5] Professor of Pharmacognosy and Biology in the Massachusetts College of Pharmacy.

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It grows in the West India Islands (6), especially in Jamaica and Martinique (7), and it has been found in Florida, Texas, southern Mexico and the northern regions of South America (6).

The root bark of *P. Erythrina* has been used by the natives of the Antilles for a great many years as an analgesic and as an agent for anesthetizing fishes, as was recorded in 1722 by the Dominican Jean Baptiste Zabet (especially in St. Vincent) (5).

In 1794 Barham pointed out in his *Hortus Americanus* that he had used the bark of this drug as an astringent tonic in the treatment of ulcers (11). In 1830 the English physician Hamilton, who lived in the Antilles, recommended this drug (5); and later, in 1884, he studied the drug after having tried it on himself successfully against tooth neuralgia, and attributed to it very active narcotic and anesthesic properties (11).

The first chemical investigation of *P. Erythrina* was reported in 1883 by Hart (12) who obtained a nearly colorless crystalline substance from the fluidextract prepared from the root bark by Parke, Davis and Co. The substance melted at 192° (uncorrected), and the

[1] An Edwin L. Newcomb Memorial Award Essay in Pharmacognosy.

[2] The author, whose address is Elias de la Cruz 15, Santiago, Chile, gratefully acknowledges the generous supply of bark, leafy stems and other parts of *Piscidia Erythrina* plants donated for this investigation by The Essex Research Foundation.

[3] Garden and Forest 4: 472. 1891.

elementary analysis gave the formula $C_{29}H_{24}O_8$. He called it "piscidia"[4] and considered it responsible for the poisonous properties of the fluidextract.

In 1898 Berberich (13) published the results of a proximate analysis of the bark of *P. Erythrina* and those of a special search for the active principle "piscidia". He used the Hart's method for the extraction and stated that the crystals separated by him possessed all the properties assigned to "piscidia" by Hart.

In 1901 Freer and Clover (14) studied the root bark of *P. Erythrina* and found that Hart's piscidia is a mixture of two very distinct bodies, one $C_{23}H_{20}O_7$ m.p. 201°, and the other $C_{22}H_{18}O_6$ m.p. 216°, the former being in great excess. They also isolated a number of crystalline substances, among them piscidic acid, $C_{11}H_{12}O_7$ m.p. 185°.

In 1919 Pittenger and Éwe (15) studied the chemistry of the drug and obtained the same results obtained by Hart and Berberich.

In 1934 Danckwortt and Schütte (16) reported the results of an exhaustive chemical investigation of the drug sold as "Cortex Piscidiae Erythrinae". Among the various substances they found was a water-soluble glucoside of saponin character.

In 1944 Russell and Kaczka (17) studied chemically the root bark and the root wood of *P. Erythrina*, isolating rotenone and a new compound "ichthynone" $C_{23}H_{20}O_7$ m.p. 203–204°.

In 1948 Costello and Butler (18) studied for the first time the chemistry and pharmacology of the stem bark of *P. Erythrina* which had first been submitted to Dr. H. W. Youngken[5] for pharmacognostic identification and had been found to be authentic. The chemical analysis was carried out for the purpose of tracing the potent substance with a view to isolation.

In 1948, Budge, Coleman and Robertson (19) reported the results of their experiments on the structure of piscidic acid (dibasic acid) $C_{11}H_{12}O_7$, this being the best defined chemical constituent of *P. Erythrina*, first isolated and examined by Free and Clover (14).

The earliest physiologic researches on the drug appear to have been done in 1880 by Dr. Isaac Ott (9) and by Nagle (20). Both found that it has narcotic properties, that it causes dilatation of the pupils, that it increases secretion of sweat, and that it causes rise of blood pressure. They compared the action of morphia and piscidin and said that they are somewhat similar.

In 1916 Delzell, Burman and Pilcher (21, 22) found that Jamaica dogwood lowers the amplitude of the contractions of the excised intestine of rabbit and of the excised uterus of guinea pig.

In 1919 Pittenger and Éwe (15) studied the standardization of the drug by chemical and physiological methods and reported that only the physiological method is useful for the purpose. The method employed was the same as that for standardization of cannabis, producing incoordination and ataxia similar to that produced by the latter, the hypnotic effect being approximately one-seventeenth as great as in cannabis.

In 1932 Drake and Spies (23) studied the toxicity of certain plant extracts on goldfish and found that 1 ml. ext. (from 0.2 gm. plant material) per l. of *P. Erythrina* caused the death of goldfish in less than 100 min.

In 1936 Hauschild (24) reported that the amorphous yellowish substance obtained from the petroleum ether extract of commercial *P. Erythrina* bark is toxic for fish and for warm-blooded animals, strongly toxic for rats and rabbits when

[4] Some authors have referred to this substance as "piscidin" or "piscidine".

[5] Professor of Pharmacognosy and Biology in the Massachusetts College of Pharmacy.

administered parenterally, but non-toxic by oral administration in doses of up to 5 mg. The same author in the same year (25) reported the results of his studies on the lethal dosage of the active substance of the drug found as "Cortex Piscidia Erythrina" for the fishes and found that it kills them in a dilution of 1:80,000,000.

In 1944 Russell and Kaczka (17) reported that extraction of the root bark or root wood of *Ichthyomethia piscipula* with petroleum ether gives a mixture of crystalline material very toxic to goldfish, and that ichthynone, one of the active principles isolated in their chemical investigation, kills goldfish at a concentration of approximately one part in a million.

In 1948 Costello and Butler (18) studied for the first time the uterine activity of the stem bark of *P. Erythrina* in different extracts. They reported that preparations of Piscidia were exceedingly potent uterine depressants, in vitro and in vivo on various laboratory animals; that the depressant substance of the drug was found in the resin, and in the extracts of alcohol, petroleum ether, ether, and chloroform; that petroleum ether was the optimum single solvent for the depressant principle; that certain fractions of the drug have the same order of uterine depression in vitro as papaverine hydrochloride, and that they exceed any of the known botanicals used for this purpose in depressant action; that Piscidia has a low relative toxicity when fed orally to rats. Costello and Butler, after other experiments, stated that all parts of the plant contain the depressant principle, the root bark being the most potent.

The latest investigation of the action of *P. Erythrina* reported in the literature is that of Sievers, Archer, Moore and Govran (26) who studied the insecticidal action of various extracts and powders of different parts of *P. Erythrina* upon adult houseflies, mosquito larvae (*Culex* sp.) and 13 other insect species, all leaf feeders. All parts of the plant were shown to be toxic to four insect species, killing 50% or more of them.

The drug began to be used more extensively in regular medical practice after publication of the experiments of Ott and Nagle. Many physicians started making use of it and began to report the results of their therapeutic tests with the fluidextract of the drug. Thus in 1883 Firth (27), Payne (28), Seifert (29), Wells (30) and Palmer (31) reported that they used it successfully in delirium tremens, for alcoholism, nervous-bilious attack, in phthisis, hysterical mania, and in nervous headache, respectively. In 1935 Reko (32) reported that the drug, together with two other plants, is an ingredient of the Mexican native tea called "Sinicuichi". In 1937 Leclerc (11) reported its value in therapeutics as an analgesic, especially in pains originating in the pelvic organs.

The histology of the root bark of *P. Erythrina* has been studied and described by Collin (4), Swaters (33), Moeller (34), Tschirch (5) and Jaeger (7).

Collin (4) established that the cork is composed of several rows of collapsed tabular cells, regularly superposed; that the cortical parenchyma possesses rectangular or slightly polyhedric cells without sclerenchyma cells; that the phloem is very developed with slightly tangentially elongated cells, slightly smaller than those of the cortical parenchyma and regularly disposed in radial series; that the medullary rays are more or less sinuous, composed of two rows of cells; and that in the phloem there are very numerous bundles of fibers and soft bast, tangentially elongated and in parallel disposition.

Swaters (33) described, at the level of the cortical parenchyma and phloem parenchyma, chlorophyllic cells, crystal cells and large lacunae containing a

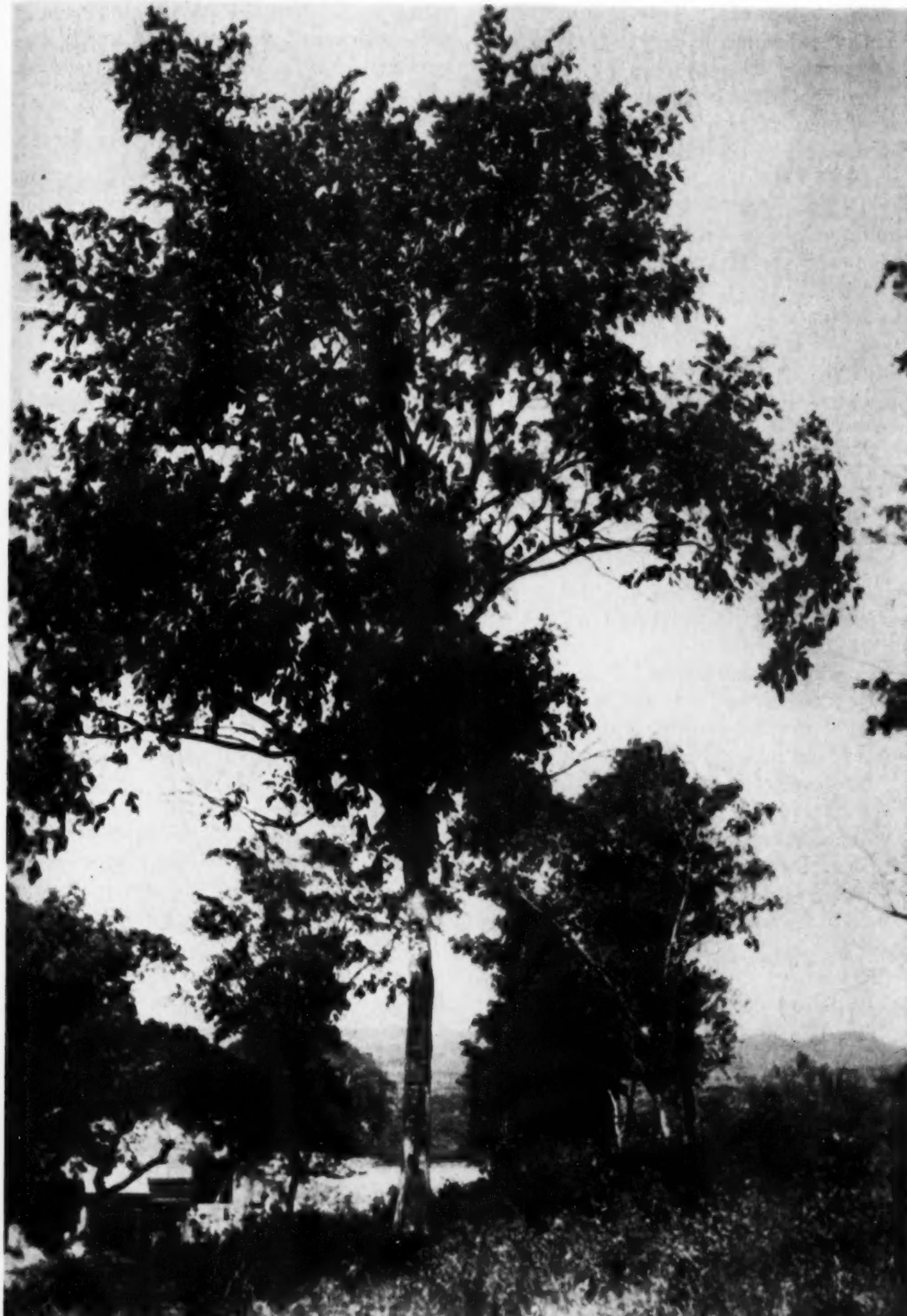


PLATE I

Jamaica Dogwood (*Piscidia Erythrina* L.). In center, a tree of this species, 35 feet in height, growing near Kingston, Jamaica. (*Photograph courtesy of H. W. Youngken*).

resinous substance. This author points out the existence of crystal cells surrounding the fiber-phloem bundles.

Moeller (34) studied the resinous substance and reported that it is easily soluble in cold absolute alcohol and saponifiable by the alkalis, and that it does not give the reaction of tannins. It is insoluble in water and in glycerine.

Tschirch (5) very briefly discussed the histology of the root bark and reported the presence of starch in all the parenchyma cells.

Jaeger (7) points out that the characteristics of this bark are the resiniferous lacunes of the cortical parenchyma, and the cells with calcium oxalate. He studied especially these crystal cells in thin sections and stated that their size is the same as that of the other cortical cells, and that the crystals are not free in the cells but partly or wholly embedded in a lignified deposit within the cells.

In 1948 Youngken (8) described the physical characteristics of the stem bark and the powdered stem bark.

A review of the histological literature on *P. Erythrina* shows that only the histology of the root bark and the powdered stem bark had been studied and described (4, 33, 34, 5, 7, 8).

The present work contains the results of a study of the anatomy of the stem bark, the stem wood and the leaves of *P. Erythrina*, previously authenticated by Professor H. W. Youngken.

Experimental Data

Piscidia Erythrina L. (Plate I)

Stem Bark

TRANSVERSE SECTION (A PLATE II).

CORK. The cork consists of many layers of rectangular to quadrangular yellowish-brown cork cells, with suberized to more or less lignified walls arranged in tier-like fashion. The cork cells have a characteristic structure, the inner and outer cell walls being usually more thickened than the side walls, thus producing ovate lumina in the centers (D Fig. 1 Plate II).

CORTEX. The cortex consists of a broad zone of square to rectangular, tangentially elongated, starch-crystal-and-tannin-bearing cortical parenchyma cells. The starch grains are single to 2–5 compound. The individual grains are spheroidal to elliptical, rounded-polygonal to plano- to angular-convex with distinct central hilum, spheroidal to 4 cleft, mostly up to 8.2 μ but frequently up to 13.2 μ in diameter[6] (D Fig. 2 Plate II). No polarization cross was observed in the grains studied under the petrographic microscope. The crystals are mostly single monoclinic prisms of calcium oxalate up to 35 μ in length; they are found in rounded cells with lignified walls. Twin crystals of calcium oxalate were also observed (D Fig. 4 Plate II). Tannin is noted in the form of irregular brown masses stained black with 1% ferric chloride solution.

Large reservoirs, elliptical to lens-shaped, with brownish-red amorphous content occur in this region. The brownish-red substance in the reservoirs is insoluble in cold and in boiling water and in 95% alcohol, in cold 50% potassium hydroxide solution, ammonia and xylol; it is soluble in cold and boiling diluted sodium hypochlorite solution, in boiling concentrated nitric acid and in boiling 50% potassium hydroxide solution. Tison and Chevalier gave the name "lignine-gomeuse" (gummy-lignin) to a substance with these characteristics[7].

PHLOEM. The phloem is a broad region consisting of a matrix of phloem parenchyma tissue traversed by wavy interrupted phloem rays, the latter separating

[6] The starch was studied in the powdered stem bark.

[7] H. W. Youngken, A Textbook of Pharmacognosy, ed. 6, The Blakiston Company, Philadelphia, 1948, p. 261.

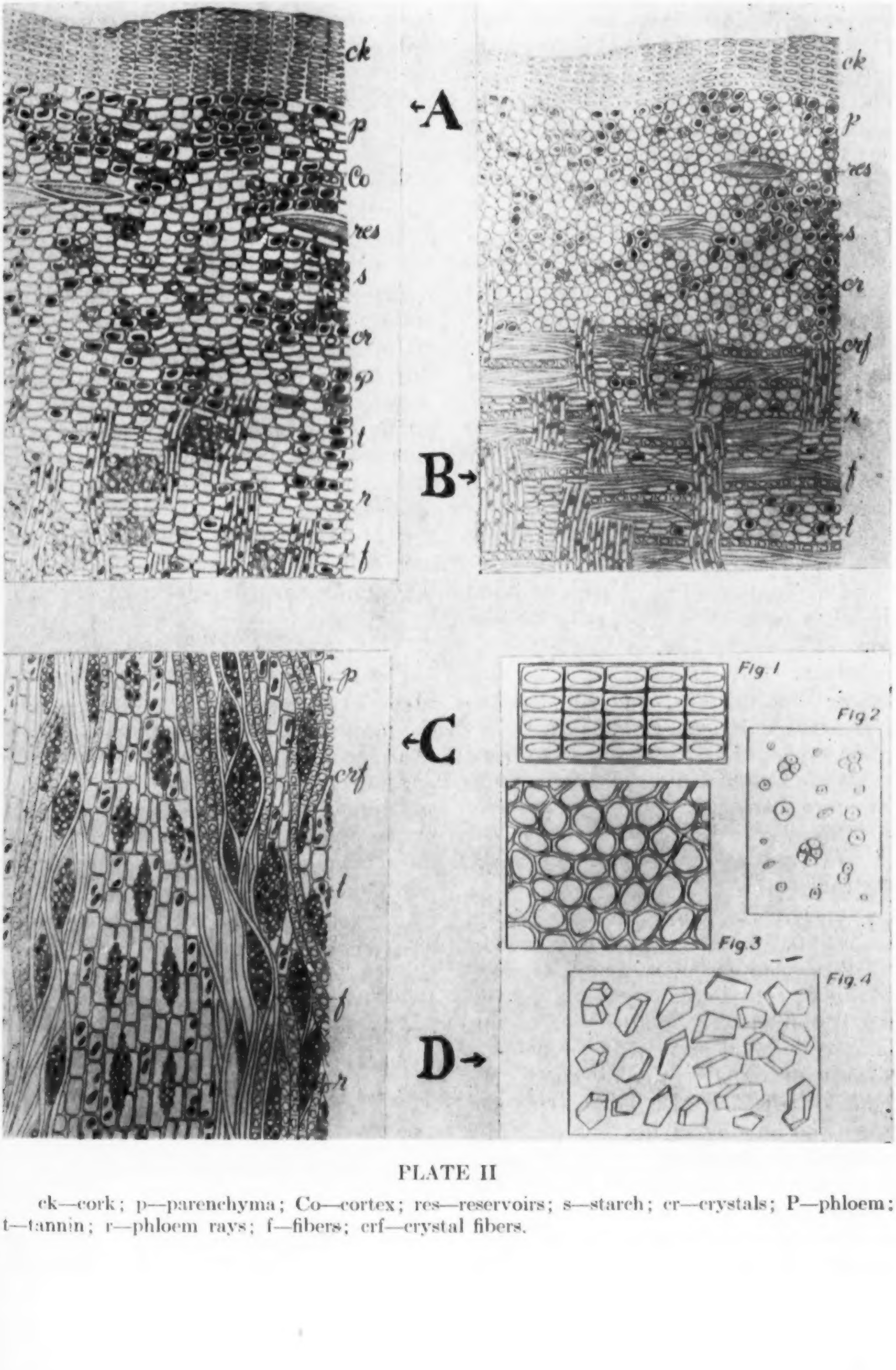


PLATE II

ck—cork; p—parenchyma; Co—cortex; res—reservoirs; s—starch; cr—crystals; P—phloem; t—tannin; r—phloem rays; f—fibers; crf—crystal fibers.

the phloem into irregular oblong areas. Each area shows numerous alternating masses of lignified fibers and soft bast. The fibers in this view are observed as polygonal cells with thick lignified walls and large and irregularly polygonal lumina. The fiber masses are surrounded by crystal fiber cells containing monoclinic prisms, less frequently twin prisms of calcium oxalate up to 35 μ in length. The parenchymatous cells are tangentially elongated and are not lignified. Many of the cells show rounded brown masses of tannin. The phloem rays consist of 1–5 (occasionally up to 6) rows of cells, radially elongated, which contain large masses of tannin and whose walls are not lignified. The separated elements of the bark are shown in H Fig. 1 Plate III.

RADIAL LONGITUDINAL SECTION (B PLATE II)

CORK. Many layers of cork cells, of the same form as in the transverse section.

CORTEX. The cortex is a broad zone composed of rounded to polygonal parenchymatous cells, some of which have lignified walls and contain a monoclinic prism of calcium oxalate; others contain tannin or starch. Large elongated secretion reservoirs with brownish-red amorphous substance are observed in some of the sections.

PHLOEM. The phloem fibers appear in longitudinally elongated discontinuous bundles, sometimes surrounded by crystal fibers containing monoclinic prisms and less frequently twin prisms of calcium oxalate. The phloem parenchyma consists of rounded to polygonal nonlignified cells, but the parenchyma between the bundles of fibers is generally observed as rectangular cells elongated in the same direction as the fibers. The phloem rays are discontinuous and cross at right angles to the other tissues. They are up to 22 rows of cells in depth. The cells of the phloem rays are rectangular and radially elongated, and many of them contain very numerous irregular brown masses of tannin.

TANGENTIAL LONGITUDINAL SECTION THROUGH THE PHLOEM (C PLATE II)

The tangential longitudinal section through the phloem shows numerous closely set spindle-shaped phloem rays, 1–5 and occasionally from 1–6 cells in width, surrounded by crystal fibers and phloem lignified fibers or by parenchymatous tissue. The phloem ray cells in this kind of section are rounded and show large, irregular, brown masses of tannin. The parenchyma cells are rectangular and longitudinally elongated, and contain large, irregular, brown, amorphous masses of tannin. Both the crystal fibers and the phloem fibers run longitudinally in wavy form surrounding the spindle-shaped phloem rays.

Powder

The powder is brown with numerous single or 2–5 compound starch grains, the individual grains spheroidal to elliptical, rounded-polygonal to plano- to angular-convex, showing a distinct central hilum, spheroidal to 4 cleft, mostly up to 8.2 μ in diameter but in some instances up to 13.2 μ. The powder shows also numerous monoclinic prisms of calcium oxalate up to 35 μ in length and occasional twin crystals; fragments of bundles of lignified fibers with adherent crystal fibers; groups of ray cells with tannin masses; and fragments of the cork, some of them in surface view (D Fig. 3 Plate II).

Stem Wood

TRANSVERSE SECTION (E PLATE III)

In transverse sections the stem wood shows alternating irregular bands of wood parenchyma and of fibers, coursing

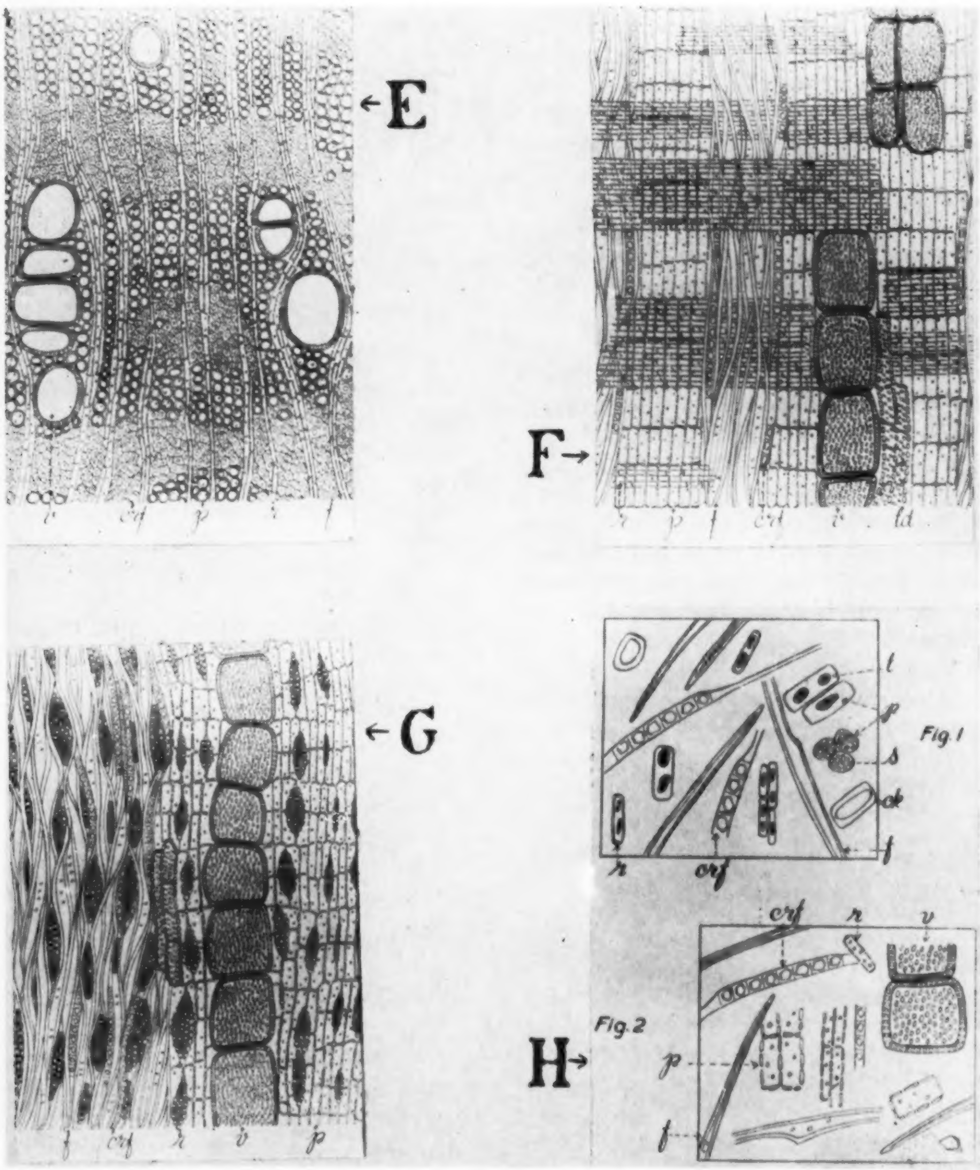


PLATE III

v—vessels; crf—crystal fibers; p—pitted parenchyma; r—wood rays or wood ray cells; f—fibers; td—tracheids; ck—cork cells; s—starch; t—tannin.

through both of which are vessels. The wood parenchyma consists of rounded cells with pitted walls. The fibers in this kind of section are polygonal and possess thick walls and irregular rounded lumina. The vessels are rounded, plano-convex, oval or elliptic, with pitted borders. They are mostly arranged singly or in groups of 2 to 4; occasionally one finds up to 9 vessels in a group. They are up to 278 μ in width. Some of them show a yellowish-brown to brown amorphous substance; and occasionally they exhibit a single perforation plate.

Surrounding the groups of wood fibers, or between them, occur some crystal fibers showing monoclinic prisms, occasionally twin prisms of calcium oxalate. The crystals are up to 35 μ in length.

The wood rays, consisting of 1–5 rows (occasionally up to 6) of radially elongated pitted cells, cross at right angles to the strands of parenchyma cells and fibers.

Very few starch grains are in the wood [8].

Parenchyma cells, fibers and vessels possess lignified walls.

The separated elements of the wood are shown in H Fig. 2 Plate III.

RADIAL LONGITUDINAL SECTION (F PLATE III)

The radial longitudinal section shows broad bands of lignified fibers surrounded by crystal fibers, and broad bands of wood parenchyma composed of rectangular elongated cells in parallel disposition and alternating with the bands of fibers. Some of the fibers display round to short slit-like pits. The parenchyma cells have lignified and pitted walls.

The wood rays are generally up to 9 rows of cells in depth but some are occasionally up to 24 rows. They cross at right angles to the bands of parenchyma and fibers. They are composed of rectangular cells which are narrower and longer than those of the wood parenchyma. Like the latter they possess pitted lignified walls.

The vessels run parallel to the fibers and wood parenchyma. They are up to 278 μ broad, are pitted and have pitted borders, and often contain a yellow substance.

Tracheids with circular, oval or elliptic bordered pits are observed.

TANGENTIAL LONGITUDINAL SECTION (G PLATE III)

The tangential longitudinal sections show broad zones of wood parenchyma alternating with broad zones of fibers. The wood parenchyma cells are rectangular, longitudinally elongated and parallel with pitted walls. The wood fibers are sometimes surrounded by crystal fibers.

The rays observed in this kind of section occur in the form of spindle-shaped areas of cells. They are from 1–5 cells in width, occasionally up to 6.

The vessels run parallel to the fibers and are up to 278 μ in diameter. They exhibit slit-like pits.

Tracheids, with circular, oval, to elliptic bordered pits, are also found in these sections.

Young Stem (I Plate IV)

TRANSVERSE SECTIONS IN DIFFERENT AGES OF GROWTH

SECTION 1. 1.5 to 1.8 mm. in diameter. The transverse section of the young stem shows the following tissues:

Epidermis. Composed of one layer of more or less conical to plano-convex cells with thick, convex, cutinized outer walls. This layer bears non-glandular hairs, generally with one or two short basal cells and an elongated pointed distal cell.

Primary cortex. Consists of four to six

[8] The starch was investigated in the powdered wood.

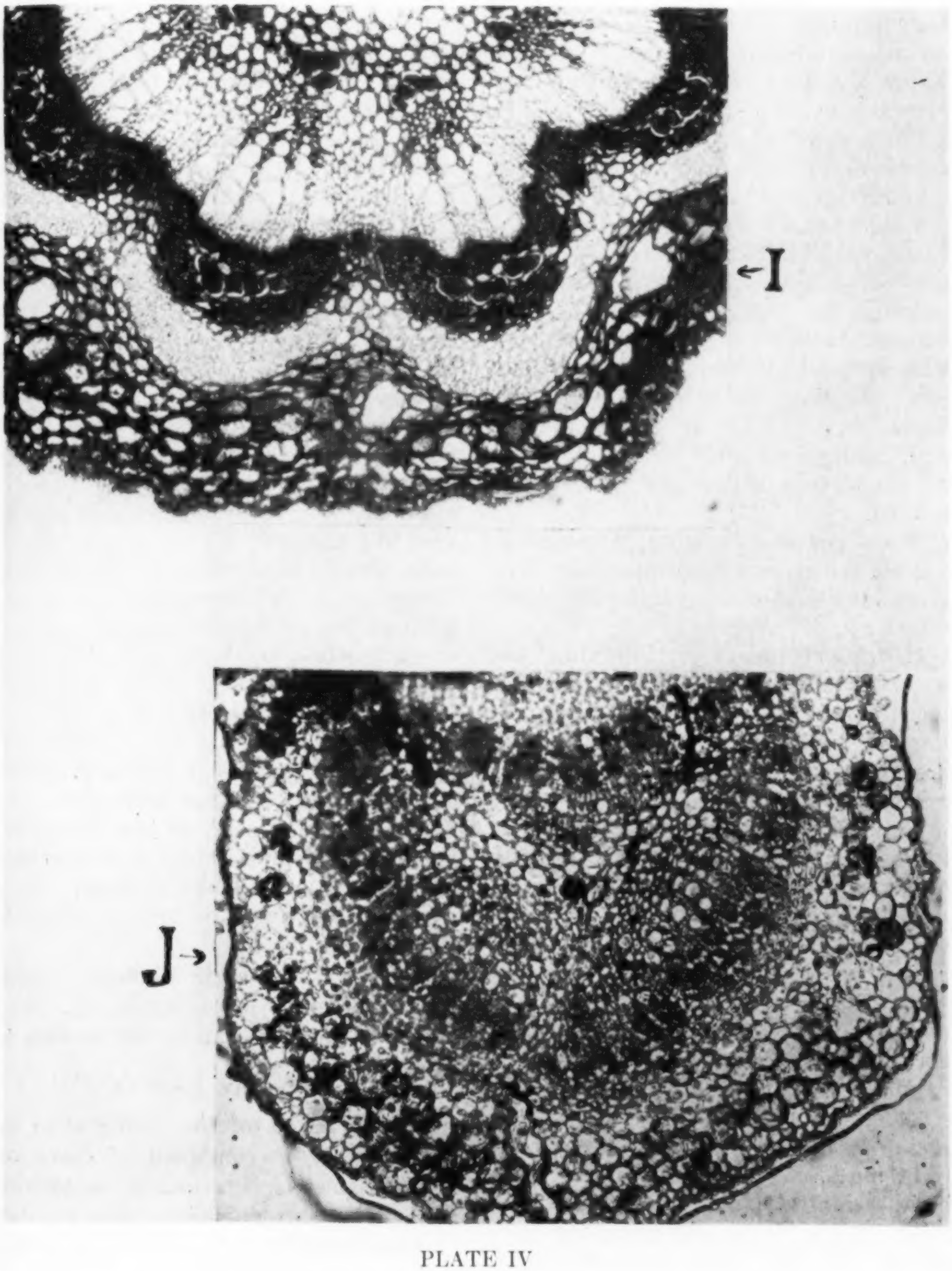


PLATE IV

layers of collenchyma cells, beneath which two or three layers of parenchyma cells are observed. Some of the cells have lignified walls, and some contain monoclinic prisms of calcium oxalate. Many of the cells have brown walls and possess a brown content. These take on a black color when treated with ferric chloride solution (tannin). Occasionally rounded secretion cells with brownish-red amorphous content are found.

Pericycle. Well developed, showing crescent-shaped groups of lignified fibers capping the exterior of the phloem masses. Surrounding the latter are cells with monoclinic prisms of calcium oxalate. Between the groups of pericyclic fibers, isolated cells or groups of cells with lignified walls are observed. These are stone cells in the process of being formed.

Primary vascular bundles. Arranged in a circle and separated by medullary rays. Each bundle shows the following structures:

1. *Primary phloem*, following the wavy form of pericyclic fibers and showing phloem cells and sieve elements. Large rounded secretion cells with brownish-red contents occur in this region, more or less disposed in rows or in groups. Cells with lignified walls, isolated or in groups, are occasionally observed in this part of the section.

2. *Cambium*, of more or less collapsed meristematic cells.

3. *Primary xylem*, composed of vessels arranged in rows, wood parenchyma and wood rays; the latter consist of many rows of cells and contain rounded iregular masses of tannin. All elements of the xylem are lignified.

Pith. Composed of pitted parenchyma cells, most of which, particularly those in the central area, possess lignified walls. Some of the cells along the margin of the pith have a brownish-red content.

The red substance in rounded cells of the primary cortex, the primary phloem and the pith has the same characteristics of solubility as has the brownish-red substance in the bark's reservoirs.

SECTION 2 [9]. 2.5 to 2.8 mm. in diameter. The cork begins to form by division of the outer layer of cells of the cortex into two layers, the outer layer becoming cork, the inner layer, a phellogen. The cork cells have the characteristics described in the bark (p. 9). The xylem is broader than in section 1.

SECTION 3. 3 mm. in diameter. In sections of this diameter some of the epidermal cells have sloughed off. Two or three layers of cork cells are observed. The phloem is slightly broader than in sections 1 and 2. Secondary phloem appears, showing quadratic groups of fibers surrounded by non-lignified parenchyma. The undulations of the pericycle are not so pronounced as in the first two sections. The xylem is markedly broader than in sections 1 and 2.

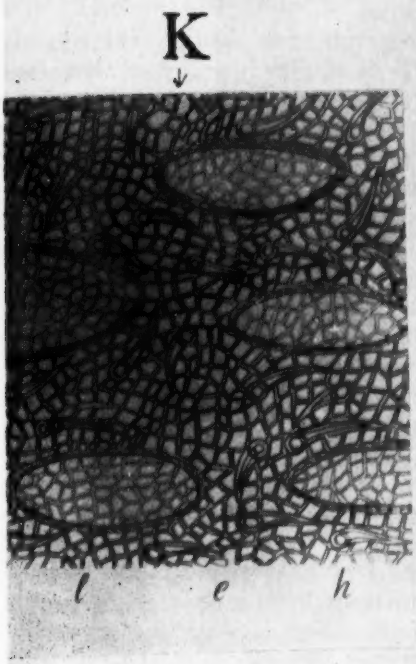
SECTION 4. 3.5 to 4 mm. in diameter. This section shows three or four layers of cork cells. Epidermal cells are still observed. In this section the wavy arrangement of the pericyclic groups has disappeared, and the groups of fibers are now seen in a more or less interrupted circle. Stone cells are formed in the parenchymatous zone of the pericycle, and groups of these extend in wedge-like fashion between the adjacent fiber masses. The xylem is broader than in the sections 1 to 4.

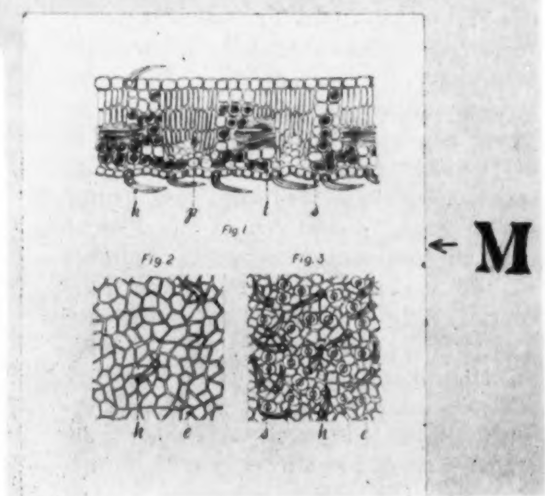
SECTION 5. 5 mm. in diameter. Most of the epidermis has sloughed off. The xylem is broader than in the section 4.

Epidermis in Surface View (K Plate V)

The epidermis of the young stem in surface view is composed of more or less isodiametric, occasionally hexagonal, cells. There are numerous hairs, similar to those described in the young stem, and spindle-shaped lenticels.

[9] Only differences are to be described in the following sections.





l—lenticels; e—epidermis; h—hairs; p—palisade cells; t—tannin; s—stomata.

PLATE V

Leaves (L Plate V)

The leaves of *Piscidia Erythrina* are imparipinnate and possess from 4–11 leaflets with articulate petiolules (8).

The leaflets are green, darker on the upper surface than on the lower surface, hairy on both sides, slightly coriaceous, ovate or elliptic, the apex acute, the margin entire or slightly sinuate, from 3 to 4½ inches in length and ½ to nearly 2 inches in breadth, with thick petiolules up to ½ inch long (3). In the herbarium material examined by the author the leaflets were from 2–5 inches in length and from 1¼–3½ inches in breadth. The principal lateral veins are parallel and extend to the border of the leaflet. The secondary veins are very numerous and join to give the lower surface of the leaflet a tesselated appearance.

TRANSVERSE SECTION THROUGH THE LAMINA OF THE LEAFLET (M FIG. 1 PLATE V)

The transverse section through the lamina of a leaflet shows the characters of a dorsiventral leaf.

The upper epidermis is composed of one layer of more or less square to rectangular elongated cells with cutinized outer walls from which scattered non-glandular hairs arise. The mesophyll consists of alternating zones of isodiametric parenchyma cells and palisade parenchyma ventrally, and spongy parenchyma dorsally. Veins course through the central region. A number of the isodiametric parenchyma cells contain a brown amorphous substance. The palisade zone consists of 2–5 layers of vertically elongated cells. The spongy parenchyma is composed of small chlorenchyma cells between which one finds numerous isodiametric cells with brown content. The brown substance of the lamina of the leaflet takes on a black color with 1% solution of ferric chloride (tannin). The lower epidermis is composed of one layer of more or less quadratic epidermal cells with cutinized outer walls, and stomata, and numerous appressed nonglandular hairs with 1–2 basal cells and an elongated distal cell.

TRANSVERSE SECTION THROUGH THE MIDRIB OF THE LEAFLET (J PLATE IV)

The transverse section through the midrib is shallowly concave above and convex below. The upper and the lower epidermises consist of one layer of more or less quadrangular cells with cutinized outer walls from which non-glandular hairs arise. Beneath both upper and lower epidermis are 4 or 5 layers of collenchyma cells, some of which contain a reddish-brown substance which takes a black color with 1% ferric chloride solution (tannin). Cells with prisms of calcium are occasionally observed. The vascular tissue shows an open collateral arrangement. Narrow rays are present, and a central "pith" occupies a great proportion of the central region. Surrounding the phloem there are interrupted arcs of pericyclic fibers below, and more or less nearly straight arcs of pericyclic fibers beneath the upper collenchyma. Some cells of the pith have irregular reddish-brown masses containing tannin. No glandular hairs are found on the leaflets.

UPPER EPIDERMIS OF THE LEAFLET (M FIG. 2 PLATE V)

The upper epidermis in surface view shows more or less polygonal cells bearing occasional hairs, the characteristics of which are described in the transverse section.

LOWER EPIDERMIS OF THE LEAFLET (M FIG. 3 PLATE V)

The lower epidermis in surface view shows polygonal cells, numerous hairs and stomata. The stomatal apparatus exhibits two subsidiary cells parallel to the guard cells. The lower epidermal

cells beneath the veins are more or less rectangular and often contain a brown substance (tannin). The veins divide the lower surface of the leaflet into a number of square meshes giving it a tessellated character.

VEIN ISLET NUMBER

Pieces of 4 sq. mm. were cut from the apex, center, margin and base of five leaves, were cleared with 5% potassium hydroxide solution, and were mounted in glycerine-jelly. They were examined under the microscope equipped with a 10 × ocular and a 16-mm. objective. The vein islets in five fields of vision of every piece were counted. The average was divided by two (approximate area of the field of vision, being exactly 1.96 sq. mm.), according to the method for the determination of vein islet number described by Youngken [10]. Only vein islets which were completely surrounded by veins were counted.

In the apex the vein islet number was from 34 to 51; in the center, from 22.5 to 47; in the margin, from 27.5 to 44.5, and in the base, from 31.5 to 42.

The average for the different parts of the leaflet were the following: apex, 40.7; center, 32.5; margin, 32.8; and base, 35.7.

The mean vein islet number for the lämina of *Piscidia Erythrina* is 35.6.

Summary

1. A review of the history, synonomy, and the uses of *Piscidia Erythrina* is given.

2. The results of a pharmacognostic study of the stem bark, stem wood, young stem and leaves of *Piscidia Erythrina* are described and illustrated for the first time.

3. The characteristics of transverse, radial-longitudinal and tangential-longitudinal sections of the stem bark are described and illustrated.

4. The powdered bark is described.

5. Transverse, longitudinal-radial and longitudinal-tangential sections of the wood are separately described and illustrated.

6. Transverse sections of 5 stages of stem growth of *Piscidia Erythrina* are described and illustrated.

7. The macroscopic and microscopic characteristics of the leaves of *Piscidia Erythrina* are described in detail and illustrated.

8. The vein islet number for the leaflet blade of *Piscidia Erythrina* is determined as 35.6.

[10] H. W. Youngken, A Textbook of Pharmacognosy, ed. 6, The Blakiston Company, Philadelphia, 1948, p. 1001.

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Utilization Abstracts

Corn Cobs. Since World War II, more than two dozen cob-processing plants have been established in eight leading corn-producing States, and in them about one million tons of cobs are being converted annually into products "now being used in the production of military equipment and supplies, stamped metal products, electroplated items, hand soaps, poultry litters, and beef cattle feeds". Nearly half of all the cobs thus used enter into the manufacture of furfural, important in the production of nylon. (Anon., *Chemurgic Digest 12(3): 12. 1953*).

Lignum Vitae. One of the most specific uses of wood is that of lignum vitae (*Guaiacum officinale* and *G. sanctum*) from Mexico, Central America and the West Indies in the manufacture of bushings at the stern end of steamship propeller shafts. The great strength and tenacity of this wood, combined with its self-lubricating property because of its resin content, adapt it for this specialized use and render it suitable for all under-water bearings. In this use the life of the wood varies from three years in large ocean liners to perhaps seven years in slower vessels.

The same qualities of extreme hardness and strength make lignum vitae unrivalled for use in wooden blocks and sheaves. Other products for which it has great value are mallets, caster wheels, bowling balls, masthead trucks, stencil and chisel blocks, cable dressers and turned novelties. Lignum vitae sheaves have been found fit for further service after more than 50 years use.

Utilization Abstract

Waxes. In 1950 a great variety of American industries bought and used 1.1 billion pounds of wax of all kinds, both imported and domestically produced. Ninety-four percent of this amount consisted of petroleum waxes, used principally in paper containers and candles but also in electrical goods, textiles, polishes, chlorinated paraffin, leather goods and fruit coatings. Vegetable waxes accounted for only 3%, most of it imported, and in 1950 such imports totaled 31.5 million pounds but dropped the following year to 26.3 million pounds. Vegetable waxes are consumed in large quantities only in polishes and carbon paper. The remaining 3% consisted of synthetic, animal and mineral waxes.

Plant waxes occur mainly as coatings on plant leaves and stems and on certain berries and grasses, with some of the rarer waxes appearing on flowers, roots and fruit. Plants producing greatest amount of wax for their weight are found mainly in hot or tropical climates in arid regions; the wax acts as a coating to impede moisture evaporation.

CARNAUBA. Most important wax in the plant group is carnauba, obtained in the semi-arid northeastern part of Brazil, where native laborers recover it from the leaves of the carnauba palm (*Copernicia cerifera*) by semi-crude methods. About 75% of carnauba is the ester myricyl cerotate. Despite much work, there is no completely successful substitute for carnauba, as the ester itself cannot be synthesized economically, and other suggested compounds lack its unique combination of properties: high melting point, hardness, ability to take high and lasting polish, and compatibility in mixtures.

High prices for carnauba tend to hold an umbrella over the chemist's efforts to duplicate the product synthetically. Users of versatile carnauba in the U.S. claim that high prices have mothered declining U.S. imports and Brazil's 9,000,000 pound surplus; moreover that "European demand" represents U.S. purchases in soft currency. Brazilian authorities state that present price levels are necessary to northern Brazil's economic welfare and to allow for growing European demand. Some price shading is said to go on through evasion by so-called "marmalade deals".

The two main uses for carnauba wax are in water emulsion floor polishes and carbon paper, each use consuming about 35% of available supplies in the U.S. Shoe, automobile and other polishes also use considerable quantities. A miscellany of other outlets includes phonograph records, insulating materials, electric batteries, candles, matches, soaps, salves and chalk. It is often used in mixtures of waxes as a melting point booster.

Of the 34 million pounds of wax used annually in polishes, about half is paraffin, one-quarter carnauba. The 9 million pounds of carnauba thus used has been an inducement for chemists to synthesize an acceptable and cheaper substitute for this expensive natural wax, but so far none has been found.

On carbon paper wax functions principally as a vehicle to carry the color and to prevent the ink from soaking completely into the paper. This annually calls for 4 million pounds of carnauba, 1 million of ouricuri, the rest of candelilla, sugar cane and mineral waxes.

Imports of carnauba wax into the U.S. (1939–1951) have ranged from a low of 11,800,000 pounds in 1947 to a high of about 22,000,000 pounds in 1941.

CANDELILLA. A hard and brittle wax found in the dry regions of northern Mexico and southern Texas, candelilla (from the stems of *Euphorbia antisyphilitica*) is composed of about 50% hydrocarbons with smaller amounts of esters and free acids. Shoe and furniture polishes are believed to consume half of its production with other uses accounting for the balance.

Principal use is in manufacture of carbon paper, floor, furniture and automobile polishes and packaged shoe stains and polishes; but it is also used in chewing gum, leather dressing, candles, cements, varnishes, sealing wax, electrical insulating compositions, phonograph records, paper size, celluloid, waterproofing and insect-proofing containers, paint remover, and as blending and hardening agent in wax mixtures.

Imports of candelilla wax into the U.S.

(1939–1951) have ranged from a low of about 2,600,000 pounds in 1948 to a high of about 11,000,000 pounds in 1943.

OURICURI. Ouricuri is a wax somewhat similar to carnauba but cheaper in price. It is recovered in the State of Bahia by crude methods—scraping from the leaf (*Cocos coronata*) by knife, melting and straining.

Uses are similar to those for carnauba, for which it is often substituted, although its higher resin content makes it less desirable. According to a Department of Commerce estimate, 44% goes into carbon paper, 35% into floor, furniture and auto polishes, 12% into packaged shoe polishes, and 9% into miscellaneous uses.

Imports of ouricuri wax into the U.S. (1942–1951) have varied from a low of about 860,000 pounds in 1942 to a high of over 3,500,000 pounds in 1946.

FIR BARK WAX. A development growing out of work on the saccharification of Douglas fir (*Pseudotsuga taxifolia*) waste wood to produce ethanol is a relatively new wax, fir bark wax. Oregon Wood Chemical Co., Springfield, Ore., plans to turn out 1.5 million pounds per year by steam distilling benzene used to dissolve the wax from the bark.

ESPARTO. Esparto wax is derived from esparto grass (*Stipa tenacissima*), a tough grass found principally in North Africa. Production is said to be about 500,000 pounds a year, of which most is consumed in Britain.

PALM. This is an interesting but relatively unknown wax obtained from the palms (*Ceroxylon andicola*) of the Colombian Andes. It is high-melting, one of the hardest natural waxes.

Raffia wax, recovered from the Madagascar sago palm (*Raphia pedunculata*) is another wax in the palm group.

SUGAR CANE WAX. Sugar cane wax is a by-product of sugar production (*Saccharum officinarum*). Hence it has considerable potential importance, for the magnitude and permanence of sugar cane operations should provide unique advantages in terms of quantity, stability of supply and cost considerations.

The yearly potential production of hard wax from the sugar mills of Cuba alone would be about 60 million pounds; this is more than the world's combined production of carnauba, ouricuri and candelilla.

Chemically the wax is more complex (66% esters, 27% free acids, 5% free alcohols, 2% hydrocarbons) than other hard commercial waxes. Moreover, it is claimed that the characteristics of the final product may be varied, depending on the initial recovery process and the final refining or treatment operation.

Experimental facilities with a capacity of 550,000 pounds per year were installed at a Cuban-American Sugar plant in Cuba, in 1942. In 1947 these were expanded to recover 1 million pounds of the crude wax, and again increased to about 2.5 million in 1952.

Refined wax is produced in a Gramercy, La., plant owned jointly by S. C. Johnson and Cuban-American Sugar Co.

Potential uses for the wax are in water-emulsion polishes, carbon paper and paste polishes; as pigment dispersers and for castings. Uses are also being sought for the resin and oil fractions obtained as by-products from the solvent extraction.

MYRTLE WAX. Principal sources of myrtle wax, derived from the fruit or berries of several species of *Myrica* shrubs, are Colombia, Mexico, South Africa and the United States. Most American myrtle wax, usually referred to as bayberry wax, is collected in New England. Main use in South Africa and America is in manufacture of festive, high-grade candles and tapers.

JAPAN WAX. This material, resembling a fat rather than a wax, is obtained from the berries of small cultivated sumac-like trees (*Rhus succedanea*, *R. vernicifera* and *R. sylvestris*) grown in Japan and China. It melts at about 50° C., is used in candles, rubber vulcanization, polishes and textile finishes. Usage (about 143,000 pounds in 1950) may grow modestly but is nowhere near the high prewar levels of 2.5–3.5 million pounds a year.

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Chemical Processing of Wood. Alfred J. Stamm and Elwin E. Harris. x + 595 pages. Chemical Publishing Co. 1953. $12.

As a result of 50 or more years advances in various fields of applied chemistry, wood has become the source of many more products than merely lumber, and an enormous literature on the subject has accumulated during the past half century. At various times this literature, so far as it has concerned particular products, for instance, paper pulp and destructive distillation, has been reviewed, but now, perhaps for the first time, a comprehensive review of the entire field of chemical processing of wood has been published, along with consideration of the more recently developed processes. The principal center of investigations in this field in the United States, if not in the world, has been the U. S. Forest Products Laboratory, of the U. S. Department of Agriculture, at Madison, Wisconsin, and it is especially fitting that this comprehensive survey has been prepared by two of the foremost investigators in the field and associated with that Laboratory.

The first five chapters of 159 pages are concerned with wood as a chemical raw material and with its constituents, structure, surface properties, and mechanical and thermal characteristics. The next two deal with physical and chemical methods of drying and of preservation. Chemically derived products occupy the remaining 382 pages, with bibliographies at the ends of the chapters, and it is the content of these chapters in particular that renders the book an outstanding contribution to the literature on the subject.

Among these products are the various forms of so-called " modified wood ", achieved by various chemical or mechanical treatments in order to enhance the dimensional stability or the mechanical properties of the woods treated. " Impreg ", " uralloy ", " arboneeld ", " compreg " and " staypak " are the names given to some of these products described in the book. Charcoal burning and papermaking, the two ldest chemical wood-processing industries, are extensively treated, and other chapters are devoted to cellulose derivatives, tree exudates, destructive distillation, wood hydrolysis and hydrogenation of wood. Each of the chapters is a review of the technical literature on its subject but each of them contains also historical and general discussions, all of which features combine to make the book the most comprehensive volume that has yet appeared on the subject.

The Wealth of India. Vol. III. Written by several contributors, published by the Council of Scientific and Industrial Research, Old Mill Road, New Delhi 2, India. xx + 236 + xxix pages; illus. 1952. Rs. 18/–.

It is again very gratifying for the management of ECONOMIC BOTANY to call attention to the publication of another volume in this outstanding encyclopaedic work on the economically important plants of one country. Though the volume covers only two letters of the alphabet, C and D, it contains about 640 entries, including over 600 vegetable species. Information on the botany, production, processing, utilization and trade regarding each of them is given. In response to constructive criticism in connection with the two previous volumes, an index is included to Indian names, regional names and common English names in the three volumes.

Races of Maize in Mexico—Their Origin, Characteristics and Distribution. E. J. Wellhausen, L. M. Roberts and E. Hernandez X. in collaboration with Paul C. Mangelsdorf. 223 pages. Bussey Inst., Harvard Univ. 1952.

It has long been known that great diversity exists in maize as cultivated in Mexico, and in 1943 the Rockefeller Foundation, in cooperation with the Mexican Ministry of Agriculture and as part of a program of maize improvement, undertook a survey of all forms native to that country. Since then

about 2,000 varieties have been collected and intensively studied with respect to their geographical distribution, vegetative characters, characters of ear and tassel, and features of physiological, genetic and cytological nature. The results of this study have provided a basis for the first time for discerning natural relationships between the many groups and for establishing a classification. These results were first published in Spanish in 1951, and the present booklet is an English edition thereof. In addition to the 60 pages with abundant illustrations devoted to descriptions of existing races in Mexico, there are chapters on classification, previous studies, antiquity of the crop in Mexico, how the races have arisen, geographical distribution and origins.

Cellulose—The Chemical That Grows. Williams Haynes. 385 pages. Doubleday & Co. 1953. $4.

It is difficult to comprehend the significance of the statement that in 1952 over 85,000,000 tons of cellulose were consumed in the United States in chemical industries, or that 40,000 tons of cellulose enter into the manufacture of photographic film every year, or that 175,000 tons of the material go into transparent wrapping sheets. Yet these are the staggering quantities, along with hundreds of others, that represent one of the most extensively developed of all types of plant utilization, that which relies on chemical conversion of the universal structural material in all plants—cellulose. And the products manufactured with such chemically treated cellulose range from paper pulp through fibers, plastics, fingernail polish and compounds to relieve stomach ulcers, to the annual sales of over $10,000,000 worth of synthetic sausage casings.

While cellulose is universally present in all plants, two particular sources of it meet the demand for this enormous and ever increasing use of it, namely, wood pulp and cotton linters; the latter are the short fibers that adhere to cottonseed after the longer fibers useful for textiles have been removed. Of the two, the latter formerly predominated, but economic as well as technological factors have long resulted in competition between the two, and in recent years wood has largely but by no means completely replaced cotton.

The industrial history and technological stages in this great modern phase of plant utilization is interestingly told in this book by an author whose previous publications have also dealt with the accomplishments of "This Chemical Age", as indicated in this title of one of them.